# Utah Science Vol. 43 No. 2, Summer 1982

# UTAH SCIENCE

UTAH AGRICULTURAL EXPERIMENT STATION SUMMER 1982 VOLUME 43 NUMBER 2

FAST-TRACK TOMATOES FOR THE HOME GROWER

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SUMMER 1982 VOLUME 43 NUMBER 2

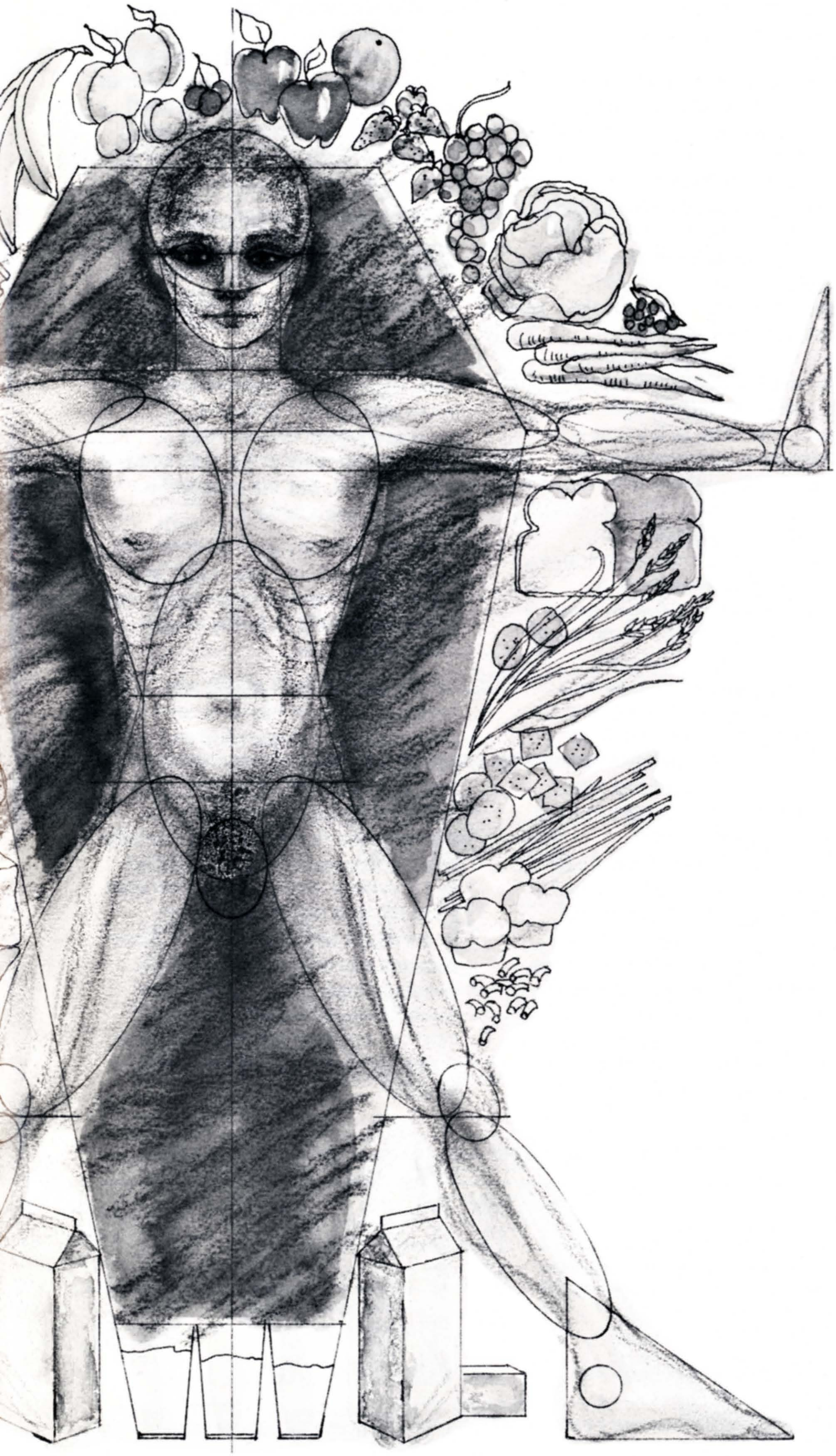
# UTAH SCIENCE

UTAH AGRICULTURAL EXPERIMENT STATION



ABOUT THE COVER

A measure of graphic license is taken to point out that growing tomatoes under clear plastic tunnels promotes faster growth and greater yield. Read more about it beginning on page 59.



# DIABETES MELLITUS

## MORTALITY IN UTAH: 1940-1980

STEPHEN H. KAN,
GAYLE E. REIBER,
and YUN KIM

### Overall Mortality

Death rates in Utah have consistently been much lower than the national rates in all our data years and for both sexes (Table 1).* If Utah had had the same age distribution as the U.S. (Table 2), its death rates would have been higher than were recorded but still substantially lower than the U.S. rates. All differences between U.S. crude death rates (U.S. CDR) and Utah's rates (Utah CDR), and between U.S. and Utah rates age-standardized to the U.S. population (Utah $ASDR_2$) were statistically significant. Utah's low mortality rates placed it third in life expectancy among all the states in 1970 (National Center for Health Statistics 1975a).

If Utah's age structure in 1980 had been the same as in 1940, the death rate in the state would have been 463.8 per 100,000 instead of 554.7. (As a matter of fact, Utah's residents 65 years and over were 5.5 percent of the population in 1940, but 7.5 percent in 1980.) The amount of mortality decline would have been 393.6 (856.4 - 463.8) instead of 302.7 (857.4 - 554.7) if the 1980 and 1940 age structures had been identical. The extent of actual decline in mortality obscured by changes in age structure thus amounts to 23 percent ( 302.7 - 393.6 ÷ 393.6).

*Data were drawn from Utah Bureau of Health Statistics and the *Vital Statistics of the United States* (National Center for Health Statistics 1943-1975) and from the five censuses from 1940 to 1980.

## Diabetes Mortality

The death rates attributed to diabetes mellitus for both sexes (combined and separately) are shown in Table 3. To identify historical trends in deaths due to specific causes, we consulted consecutive revisions of the International Classification of Diseases, Adapted for Use in the United States (ICDA). The ICDA had its Fifth Revision in 1938 and its Ninth Revision in 1979. With respect to diabetes, the comparability ratios between consecutive revisions are as follows:

Sixth Revision (1949-1957) to Fifth Revision (1938-1948): 0.58 (National Office of Vital Statistics 1950);
Seventh Revision (1958-1967) to Sixth Revision: 1.01 (National Center for Health Statistics 1958);
Eighth Revision (1968-1978) to Seventh Revision: .9971 (National Center for Health Statistics 1975b);
Ninth Revision (1979-present) to Eighth Revision: .9991 (National Center for Health Statistics 1980).

The Fifth Revision of the ICDA overstated diabetes mellitus as the underlying cause of death, with the degree varying with the age groups. (For detailed discussions of this situation, see National Office of Vital Statistics 1950.) The figures in parentheses in Tables 3 and 4 represent the 1940 diabetes death rates adjusted downward for the overstatement.

Utah's diabetes mortality fluctuated between 1940 and 1960, rose acutely in 1970, and declined from 1970 to 1980. The 1970 upsurge was experienced throughout the U.S., but less dramatically. For both Utah and the U.S., the death rate in 1970 was higher than that in 1940 (as adjusted for overstatement by the Fifth Revision of ICDA). Reasons for the sudden increase are not clear.

Utah's diabetes crude death rate has been lower than the national rates throughout the data period. An inverse relationship was observed in 1970, however, in terms of the age-standardized rate. Specifically, if Utah had had the same age structure as the nation (Table 2), its diabetes death rates in 1970 would have been 20.6 per 100,000 persons, versus 18.9 for the U.S. The predominately young population in Utah may be obscuring factors that are operating on diabetes deaths. In 1980, the median ages were 23.7 years in Utah and 30.0 in the U.S.

Sex differentials in overall mortality, as measured by the percent differences in age-standardized rates (Utah $ASDR_1$), had been widening until 1980, with females gaining a much more favorable position (Table 1). With respect to diabetes, the difference between sexes has been narrowing as their crude death rates tend to converge. That convergence is attributable to: (1) excess male mortality for ages 25 to 64, and (2) a narrowing of female-male mortality differences for ages 65 and over (Table 4). In terms of age-standardized rates, there has been a slight increase in male diabetes mortality since 1970.

Deaths due to diabetes, as do those associated with most chronic disease, increase with age (Table 4). Diabetes mortality for ages under 15 has been virtually eliminated since 1960. For ages 25 to 54, and for 65 and over, there has been a slightly increasing trend up to 1970 and then decreased. For the age group 55 to 64, the trends diverge—generally increasing for males and decreasing for females.

## What We Know in 1980

1. Utah's overall death rates have been much lower than the U.S. rates for all data years between 1940 and 1980 and for both sexes. The differences have been statistically significant for both crude and standardized rates.
2. Up to 23 percent of the actual decline in mortality in Utah since 1940 has been obscured by the increasing proportion of aged individuals in the state's population.
3. Diabetes mortality in Utah fluctuated from 1940 to 1960, experienced an acute upsurge in 1970, and decreased from 1970 to 1980. Diabetes mortality in the U.S. showed similar trends, but the upsurge in 1970 was less dramatic.
4. Diabetes mortality was lower in Utah than in the U.S. in 1940, 1950, and 1960, but an inverse relationship was observed in 1970 in terms of age-standardized rate.
5. As the gap between males and females in overall mortality (percent differences in age-standardized rate) has widened, males have been losing their favorable position relative to diabetes mortality. The recent convergence in the diabetes mortality rates of the two sexes is attributed to: (1) excess male mortality for ages 25 to 64, and (2) decreasing differences for ages 65 and over. Since diabetes mortality under age 55 is generally regarded as preventable (Utah Bureau of Health Statistics 1981, p. 41), the high male mortality in the middle years deserves special attention.


REFERENCES

National Center for Health Statistics

1943-1975 *Vital Statistics of the United States* 1939 to 1971 Public Health Service, Washington, D.C.

1958 "Comparability of Mortality Statistics for the Sixth and Seventh Revisions, United States" Public Health Service, Washington, D.C.

1975a "Utah State Life Tables: 1969-71" Public Health Service Washington, D.C.

1975b "Comparability of Mortality Statistics for the Seventh and Eighth Revisions of the International Classification of Diseases, United States" by A. J. Klebba and A. B. Dolman Public Health Service Washington, D.C.

1980 *Monthly Vital Statistics Report* (Supplement), Vol. 28, No. 11 Public Health Service Washington, D.C.

National Office of Vital Statistics

1950 *Current Mortality Analysis*, Vol. 7, No. 13 Public Health Service Washington, D.C.

Utah Bureau of Health Statistics

1981 *Utah Vital Statistics, 1979*, Salt Lake City: Utah State Department of Health.

**TABLE 1. Crude death rates (CDR) and age-standardized death rates (ASDR) (per 100,000 persons) for all causes of death: U.S. and Utah, 1940-1980.**

| | BOTH SEXES | | | | MALE | | | | FEMALE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | U.S. CDR | Utah CDR | Utah $ASDR_1$ | Utah $ASDR_2$ | U.S. CDR | Utah CDR | Utah $ASDR_1$ | Utah $ASDR_2$ | U.S. CDR | Utah CDR | Utah $ASDR_1$ | Utah $ASDR_2$ |
| 1940 | 1060.0 | 857.4 | 857.4 | 961.9 | 1178.1 | 972.5 | 972.5 | 1091.4 | 941.0 | 739.3 | 739.3 | 829.7 |
| 1950 | 964.4 | 726.5 | 665.7 | 872.8 | 1105.8 | 861.2 | 801.4 | 1029.1 | 824.8 | 589.2 | 529.6 | 712.1 |
| 1960 | 942.5 | 674.4 | 577.3 | 841.5 | 1088.9 | 784.9 | 706.0 | 965.6 | 800.3 | 564.1 | 455.0 | 713.4 |
| 1970 | 946.6 | 665.4 | 523.1 | 829.8 | 1090.8 | 773.3 | 668.1 | 966.8 | 809.8 | 559.9 | 401.6 | 718.9 |
| 1980 | — | 554.7 | 463.8 | — | — | 633.2 | 564.2 | — | — | 478.2 | 373.5 | — |

—Data not available

NOTE: For Utah $ASDR_1$, the standard population is the Utah 1940 population; for Utah $ASDR_2$, the standard populations are the U.S. populations of corresponding years. Three-year averages (e.g., 1939-1940-1941) were used in computing all rates but those for 1980.

**TABLE 2. Population by age, number, and percent: Utah and the United States; April 1, 1980**

| | Utah | | United States | |
|---|---|---|---|---|
| Age Group | Population | Percent of Total | Population | Percent of Total |
| Total | 1,461,037 | 100.0 | 226,504,825 | 100.0 |
| Under 5 | 189,962 | 13.0 | 16,344,407 | 7.2 |
| 5- 9 | 146,187 | 10.0 | 16,697,134 | 7.4 |
| 10-14 | 125,681 | 8.6 | 18,240,919 | 8.1 |
| 15-19 | 138,903 | 9.5 | 21,161,667 | 9.3 |
| 20-24 | 155,676 | 10.7 | 21,312,557 | 9.4 |
| 25-29 | 135,087 | 9.2 | 19,517,672 | 8.6 |
| 30-34 | 105,688 | 7.2 | 17,557,957 | 7.8 |
| 35-39 | 79,178 | 5.4 | 13,963,008 | 6.2 |
| 40-44 | 63,628 | 4.4 | 11,668,239 | 5.2 |
| 45-49 | 57,021 | 4.0 | 11,088,383 | 4.9 |
| 50-54 | 55,845 | 3.8 | 11,708,984 | 5.2 |
| 55-59 | 52,701 | 3.6 | 11,614,054 | 5.1 |
| 60-64 | 46,260 | 3.2 | 10,085,711 | 4.5 |
| 65 + | 109,220 | 7.5 | 25,544,133 | 11.3 |

Source: "Age, Sex, Race, and Spanish Origin of the Population by Regions, Division, and States: 1980," *1980 Census of Population*, Supplementary Reports, PC80-S1-1, Bureau of the Census, U.S. Dept. of Commerce, issued May 1981.


ABOUT THE AUTHORS

Stephen H. Kan completed MS degrees in Sociology and Applied Statistics, and holds a PhD in Sociology from Utah State University. He is presently employed as a statistician-demographer at the Bureau of Health Statistics, Utah Department of Health, in Salt Lake City.

Gayle E. Reiber is the director of the Bureau of Chronic Disease Control, Utah Department of Health, Salt Lake City.

Yun Kim is professor of Sociology and the director of Population Research Laboratory at Utah State University.


**TABLE 3. Crude death rates (CDR) and age-standardized death rates (ASDR) (per 100,000 persons) for Diabetes Mellitus: U.S. and Utah, 1940-1980**

| | BOTH SEXES | | | | MALE | | | | FEMALE | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| YEAR | U.S. CDR | Utah CDR | Utah $ASDR_1$ | Utah $ASDR_2$ | U.S. CDR | Utah CDR | Utah $ASDR_1$ | Utah $ASDR_2$ | U.S. CDR | Utah CDR | Utah $ASDR_1$ | Utah $ASDR_2$ |
| 1940 | 25.8 | 18.7 | 18.7 | 22.4 | 19.2 | 14.4 | 14.4 | 17.1 | 32.4 | 23.2 | 23.2 | 27.8 |
| | (15.0) | (10.8) | (10.8) | (13.0) | (11.1) | (8.4) | (8.4) | (9.9) | (18.8) | (13.5) | (13.5) | (16.1) |
| 1950 | 16.4 | 11.3 | 10.5 | 14.5 | 12.5 | 8.9 | 8.4 | 11.5 | 20.3 | 13.8 | 12.6 | 17.7 |
| 1960 | 16.4 | 10.7 | 9.3 | 14.1 | 13.4 | 9.2 | 8.4 | 11.9 | 19.3 | 12.3 | 10.2 | 16.3 |
| 1970 | 18.9 | 15.8 | 12.2 | 20.6 | 15.8 | 14.7 | 12.4 | 19.2 | 21.8 | 16.8 | 11.9 | 22.6 |
| 1980 | — | 11.6 | 9.6 | — | — | 11.1 | 9.9 | — | — | 12.2 | 9.2 | — |

—Data not available

NOTE: For the Utah $ASDR_1$, the standard population is the Utah 1940 population; for the Utah $ASDR_2$, the standard populations are the U.S. populations of corresponding years. Figures in parentheses are the 1940 rates adjusted for estimated overstatement of diabetes deaths by the Fifth Revision of the International List of Causes of Death.

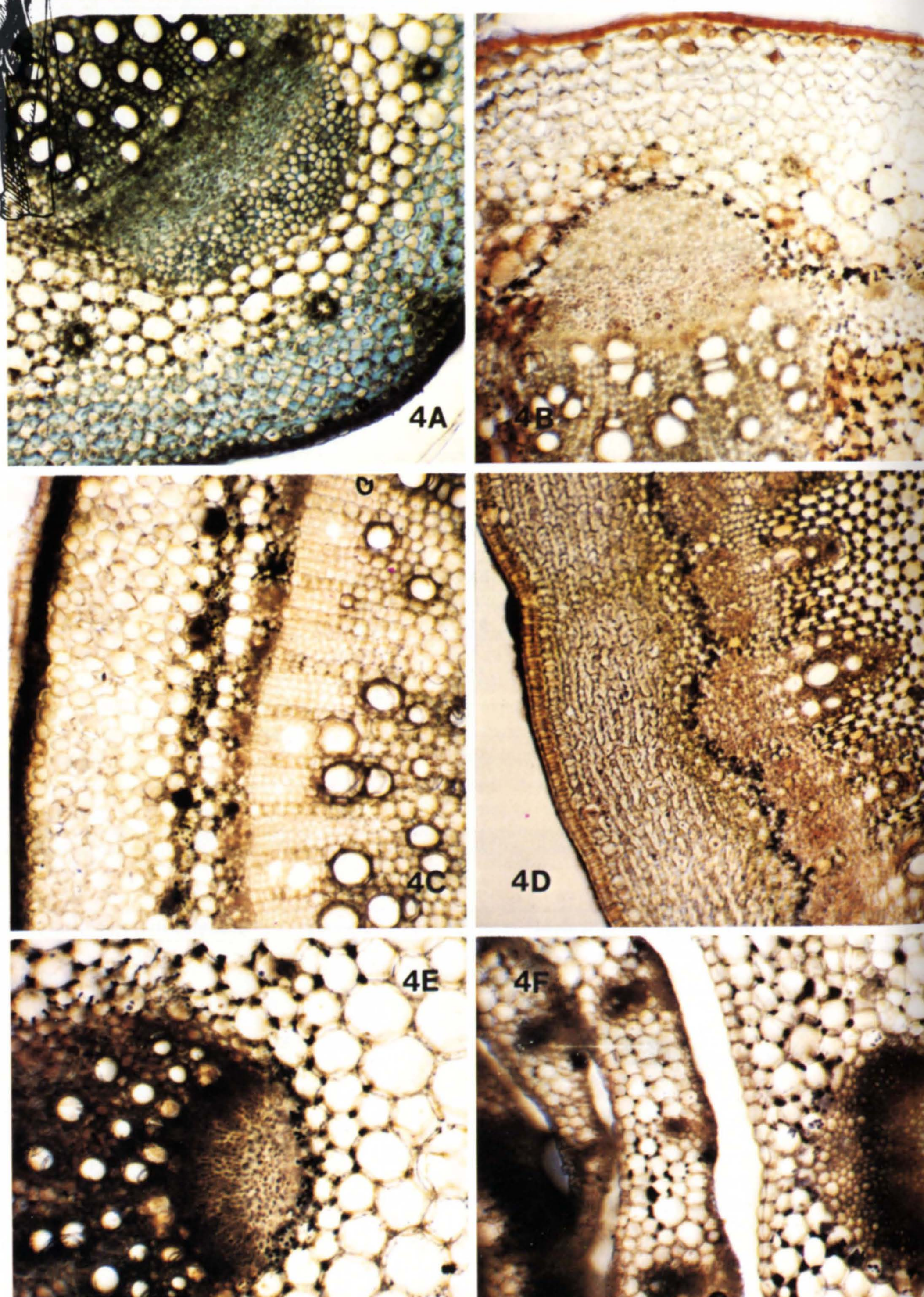
**TABLE 4. Age-specific death rates (per 100,000 persons) for diabetes mellitus: Utah, 1940-1980**

| | BOTH SEXES | | | | | MALE | | | | | FEMALE | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1940 | 1950 | 1960 | 1970 | 1980 | 1940 | 1950 | 1960 | 1970 | 1980 | 1940 | 1950 | 1960 | 1970 | 1980 |
| 0-14 | 1.5(1.3) | 0.4 | 0.3 | 0.0 | 0.0 | 1.5(1.3) | 0.6 | 0.0 | 0.0 | 0.0 | 1.6(1.4) | 0.3 | 0.6 | 0.0 | 0.0 |
| 15-24 | 3.7(3.8) | 1.2 | 1.0 | 0.6 | 1.0 | 3.0(3.1) | 0.6 | 0.5 | 0.6 | 0.7 | 4.3(4.4) | 1.7 | 1.4 | 0.6 | 1.3 |
| 25-34 | 2.4(1.8) | 2.2 | 3.8 | 3.1 | 3.3 | 3.2(2.4) | 1.9 | 4.1 | 4.1 | 5.0 | 1.6(1.2) | 2.6 | 3.6 | 2.0 | 1.7 |
| 35-44 | 6.2(4.7) | 1.9 | 2.9 | 5.3 | 4.2 | 6.1(4.6) | 0.8 | 4.4 | 6.9 | 7.1 | 6.2(4.7) | 3.1 | 1.3 | 3.7 | 1.4 |
| 45-54 | 11.3(6.4) | 8.8 | 7.2 | 9.2 | 9.7 | 11.0(6.3) | 8.1 | 7.9 | 14.1 | 9.0 | 11.7(6.7) | 9.6 | 6.5 | 4.6 | 10.5 |
| 55-64 | 52.8(6.4) | 32.3 | 27.1 | 30.6 | 22.2 | 26.5(15.1) | 22.1 | 27.3 | 32.2 | 28.9 | 80.6(45.9) | 42.9 | 26.9 | 29.1 | 15.8 |
| 65-74 | 188.4(105.5) | 85.0 | 76.2 | 104.5 | 64.9 | 138.2(77.4) | 62.1 | 58.3 | 94.3 | 62.0 | 237.9(133.2) | 107.3 | 92.6 | 113.0 | 67.3 |
| 75-84 | 292.9(169.9) | 187.2 | 152.1 | 236.6 | 159.8 | 271.8(157.6) | 189.7 | 139.4 | 229.7 | 162.9 | 312.4(181.2) | 185.1 | 162.1 | 241.5 | 157.7 |
| 85 + | 145.9(84.6) | 253.3 | 235.8 | 294.6 | 271.1 | 58.4(33.9) | 234.5 | 223.0 | 340.1 | 298.9 | 158.2(91.8) | 267.6 | 244.8 | 265.2 | 256.8 |

NOTE: Figures in parentheses are the 1940 rates adjusted for estimated overstatement of diabetes deaths by the Fifth Revision of the International List of Causes of Death.

FRANK B. SALISBURY,
JULIANNE E. SLIWINSKI,
WESLEY J. MUELLER, and
CHAUNCY S. HARRIS

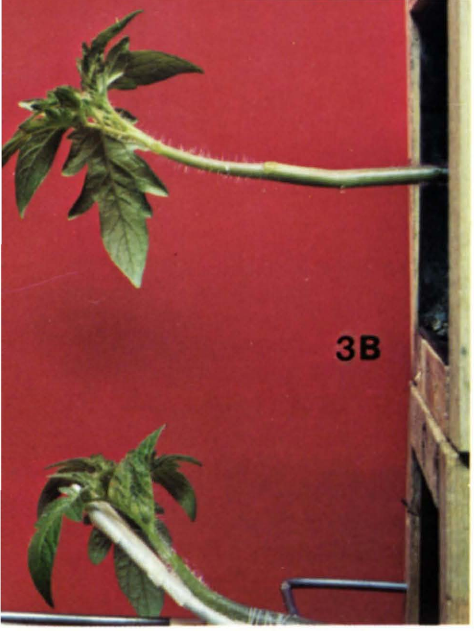





# HOW STEMS BEND UP

AS DESCRIBED IN THE LAST ISSUE OF UTAH SCIENCE, we have been investigating *gravitropism* of leafy green stems. In this article, we explore further aspects of why a plant laid on its side bends upward at its stem tip.

Laid on its side in either the light or the dark, a plant's stem or stems will bend up at the tip(s) in a direction opposite to the source of the gravitational field (Figure 1). Roots, especially if they have previously been exposed to light, will grow downward after being placed in a horizontal position. Leaves often respond to gravity separately from the stems. That is, if a stem is held in a horizontal position so that it cannot bend up but leaves are left free, they usually orient themselves so that they are more or less parallel to the earth's surface, as shown in Figure 1.



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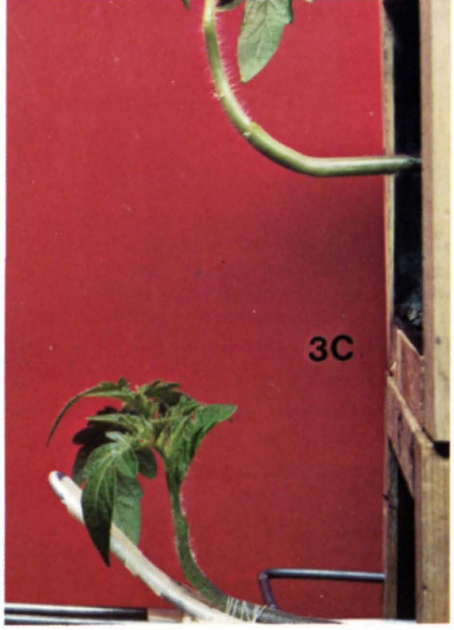

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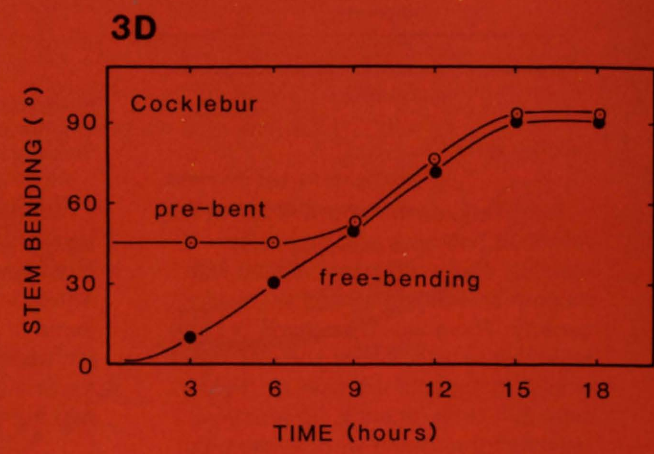


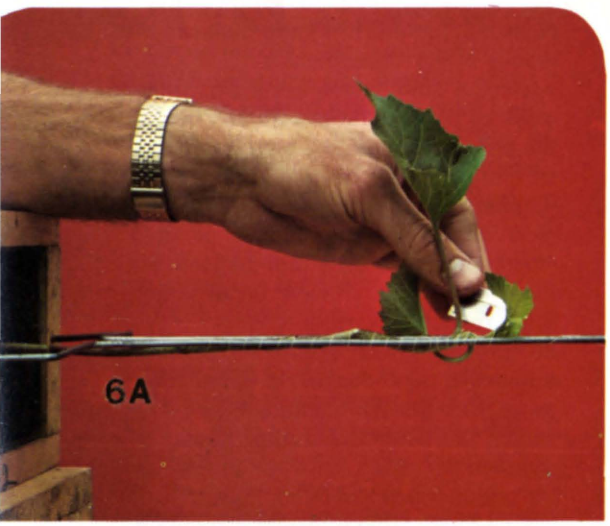

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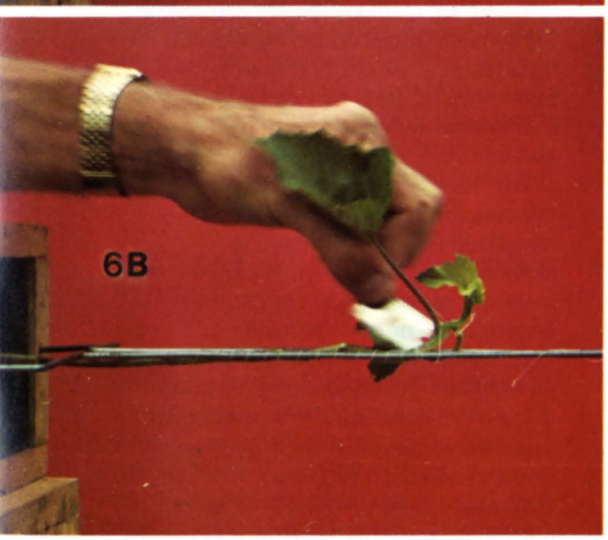


6B

6C

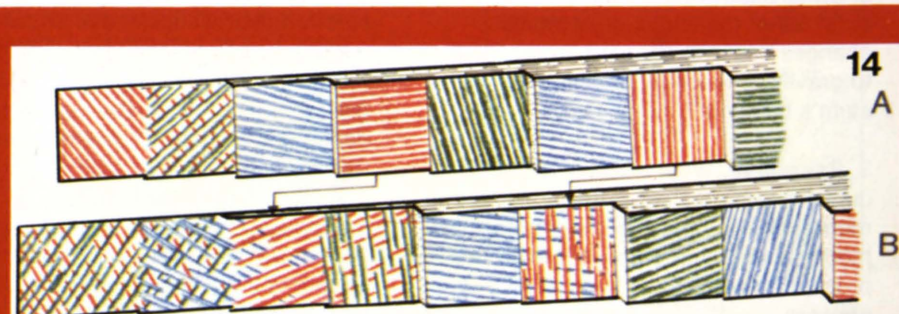
**FIGURE 1.** Three cocklebur plants and a castorbean plant that have bent upward after having been turned so their stems were horizontal. Enough leaves have been trimmed away from the upper plant (cocklebur) to show the bent stem. The bottom two cocklebur plants have been tied between wires in a horizontal position so their stems could not bend. Note how their leaves (as well as the leaves of the other two plants) have assumed a horizontal position. The plants had been on their sides for about 24 hours when the photograph was taken.

**FIGURE 3.** Gravitropic response of a pre-bent tomato plant (bottom of photographs) compared with a free-bending plant (top). **A.** Time zero when the plants were turned to the horizontal position; bottom plant has been bent upwards as in Figure 2B. **B.** Five hours later: A little before the free-bending plant reaches 45°, the pre-bent plant begins to bend away from the wire framework. **C.** Condition of the plants after twelve hours. **D.** A graph from a similar experiment showing degree of stem bending as a function of time for a prebent and a free-bending plant. (Data for the graph from Julianne Sliwinski.)

**FIGURE 4.** Some free-hand cross sections of stems, petioles, and coleoptiles stained with iodine to show starch grains (amyloplasts). **A.** Cross section of a cocklebur stem stained with toluidine blue 0 but not with iodine. The cells with light blue thickenings in the corners (cell walls) are collenchyma cells and may be important in gravitropic bending. **B.** Cross section of a cocklebur stem stained with iodine. Note the row of cells with nearly black starch grains. **C.** Cross section of a tomato stem. Note again the well-defined starch sheath separated from the conducting tissues by a layer of mostly empty cells. **D.** Cross section of a castorbean stem with a well-defined starch sheath just outside the vascular tissues. **E.** Cross section of the leaf-stem (petiole) of a cocklebur plant. Cells containing starch grains are again close to the vascular bundle (conducting cells). **F.** Cross section of a germinating corn seedling. Tissue on the right with starch grains close to the vascular bundle is the coleoptile. Tissue on the left shows cross sections of the first leaves. The coleoptile is the whitish sheath that protects the first leaves of grass seedlings. (Micrographs were taken by Chauncy Harris.)

**FIGURE 6.** Rapid bending of a cocklebur stem that has been restrained in the horizontal position for 72 hours. **A.** Just before the restraining threads were cut. **B.** Cutting the restraining threads. **C.** Condition of the stem a few seconds after the threads were cut.

**FIGURE 14.** Diagrammatic illustrations showing the wall structure of an epidermal cell of a bean epicotyl. **A.** The wall of a young growing cell. **B.** The wall of a growing cell of medium age, showing the change in microfibril orientation. Microfibrils (strands of cellulose) in the outer layers are predominantly transverse to begin with. These become stretched until the layers appear almost random. The last layers deposited as a cell matures are predominantly longitudinal (Adapted from Takeda and Shibaoka 1981.)



The phenomenon of gravitropism has mystified botanists and others for millenia, and it has been studied with modern scientific methods for over a century. There would be much intellectual satisfaction in knowing how it works: why plants are always "right-side-up." Until recently, no practical reasons for knowing were evident, but with the possibility of growing higher plants for long durations in the weightless environment of an orbiting space vehicle, understanding gravitropism takes on some practical significance. Imagine wheat or soybean stems and leaves growing every which way in random directions! Can we orient them properly with light? Or would understanding gravitropism suggest other solutions?

## GRAVITROPISM

Orientation of plant parts in relation to a gravitational field is *gravitropism* (tropism = orientation by an organism or one of its parts by turning or curving in a way determined by the source of stimulation). There are three kinds of questions about the process:

1. **Perception.** How does a plant part "know" which way is up or down? Where in the plant is the perception mechanism located? What part of the plant or of its cells or cell parts actually responds to gravity? It has been especially difficult to answer these questions for plants because they do not have specific organs for virtually every function as animals do.

2. **Transduction.** Whatever the perception mechanism is, how does it translate or transduce its message of orientation to the cells in the stem, root, or other organ where orientation occurs? What metabolic or hormonal changes occur in the stem in response to gravity, thereby influencing the stem's behavior?

3. **Response.** What actually happens during gravitropic bending? In stems and roots, cells on one side grow more than those on the other side—but even this process is less simple than it first appears.

We devised experiments to test ideas about these three aspects of the gravitropic response. In our previous article in UTAH SCIENCE, we detailed some of the problems of transduction: the possible roles of the growth hormone auxin (probably indoleacetic acid) and the gaseous hormone ethylene.

## SEARCHING FOR AMYLOPLASTS

Our studies of the perception question arise from a hypothesis suggested 80 years ago, which has been controversial ever since! It was suggested that cellular organelles called *amyloplasts,* each of which contains at least one, and usually more starch grains, settled within plant cells in response to gravity. Early workers observed that amyloplasts with their starch grains did indeed settle to the bottom of cells in an upright plant but shifted to the "side" in a stem laid on its side.

There have been decades since this concept was introduced when most plant physiologists accepted the idea of amyloplasts as gravity perceptors. The organelles were called *statoliths,* a term used for gravity perceptors in certain animals. At other times, most plant physiologists have doubted the amyloplast-statolith theory and sought other explanations. It has been reported, for example, that certain plant organs without starch nevertheless respond to gravity. There was also a report in the mid-1960s that plants could be depleted of their starch without abolishing the gravitropic response (although it was slowed). Right now, the statolith idea is widely accepted, although there are still a few doubters. Most of the responding organs supposedly without starch have been reexamined, and starch grains have been found. Careful studies with electron microscopes have shown that the gravitropic response *is* abolished when starch is *completely* depleted from the cells. (Of course, the treatments that deplete starch could have other effects that abolish the gravitropic response.)

As we studied the literature of gravitropism, we went through our own period of doubt. We wondered whether a stem laid on its side might detect its own weight to respond to the gravitational field. As Figure 2 shows, any long object held at one end in a horizontal position will be compressed on its bottom side and stretched on the top. Does a plant stem respond by growing away from the compressed side and toward the side being stretched? We felt certain that earlier workers must have asked this simple question, but it seemed easier to do the experiment than to make a detailed search of the published literature! Figure 3 shows the results of the experiment.

Control plant stems were laid on their sides as usual; others were tied below the bending region to a small framework so that they were bent 45° upward (Figure 3). Bending reversed the tension/compression so that cells on top (inside the bend) were compressed, and those on the bottom were under tension. If the response were to tension/compression, such a stem should attempt to bend downward rather than away from gravity. Instead, Figure 3 shows that when the control stems reached 45°, the stems tied to the framework began to bend upward (beyond 45°). These results eliminated the tension/compression hypothesis. (Incidentally, we did find that earlier plant physiologists had considered the theory and rejected it with experiments similar to ours.)

We have found amyloplasts containing starch grains in all stems we have studied. Cells containing amyloplasts do not occur randomly in leafy stems, however. They form a sheath or layer of cells inside and concentric with the stem surface, but just outside the conducting tissues (Figure 4). In coleoptiles (the hollow organs that surround the first leaves in grass seedlings, much starch is concentrated in the tip cells, and some cells internal to the transporting tissues also contain starch. As in the early work (mostly with root tips), we demonstrated that amyloplasts with their starch grains are quite capable of settling in stems that are laid on their sides (Figure 5).

## THE RESTRAINED GRAVITROPIC RESPONSE

In connection with other experiments we were doing, we put plants into large plastic containers, filled the containers with an insulating material, vermiculite (to immobilize leaves), and laid the containers on their sides. This led to a fascinating and serendipitous observation. When the vermiculite was poured out several hours later, we could see the plant stem suddenly (within one to ten seconds) bend so that the tip was essentially vertical, as it would have been if not restrained by the vermiculite. That is, as the stems were held in place by the vermiculite, they were undergoing the same changes that would have taken place if they had been free to bend.

Instead of packing in vermiculite, we now place a stem between two wires and wrap the wire/plant unit with threads. After some hours, we cut the threads with a razor blade and watch the rapid upward bending (Figure 6), which is more extensive for plants left in the dark than for plants in the light.

After considerable searching, we found a paper written by Anne Bateson and Francis Darwin in 1888 in which they described restraining and later releasing a plant part. They noted that the rapid upward bending was a "well-known result." Nevertheless, we have found no more recent references, so this "well-known result" may have been overlooked since 1888. We have pursued this lead to formulate fundamental and interesting questions.

## THE MECHANICS OF GRAVITROPIC BENDING

In one series of studies, we tried to answer two questions: What happens on a macroscale at the stem surface when stems are restrained and then released? And what happens at the microscale of the stem cells?

We first examined upright control plants, as well as plants laid on their sides and allowed to bend freely. One way is to mark plants as in Figure 7A by attaching small glass beads with stopcock grease and then photograph them at intervals. Distances between the beads can be measured on the photographs, and the changes in distances can be plotted as a function of time, as in Figure 7B. Growth on the bottom of cocklebur or castorbean

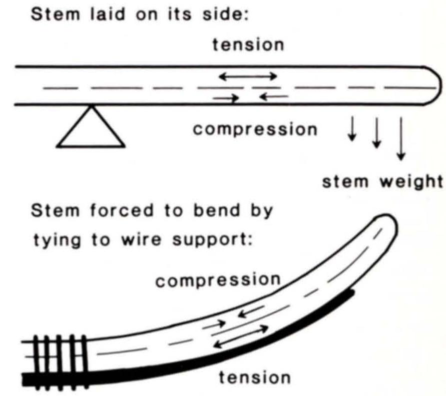
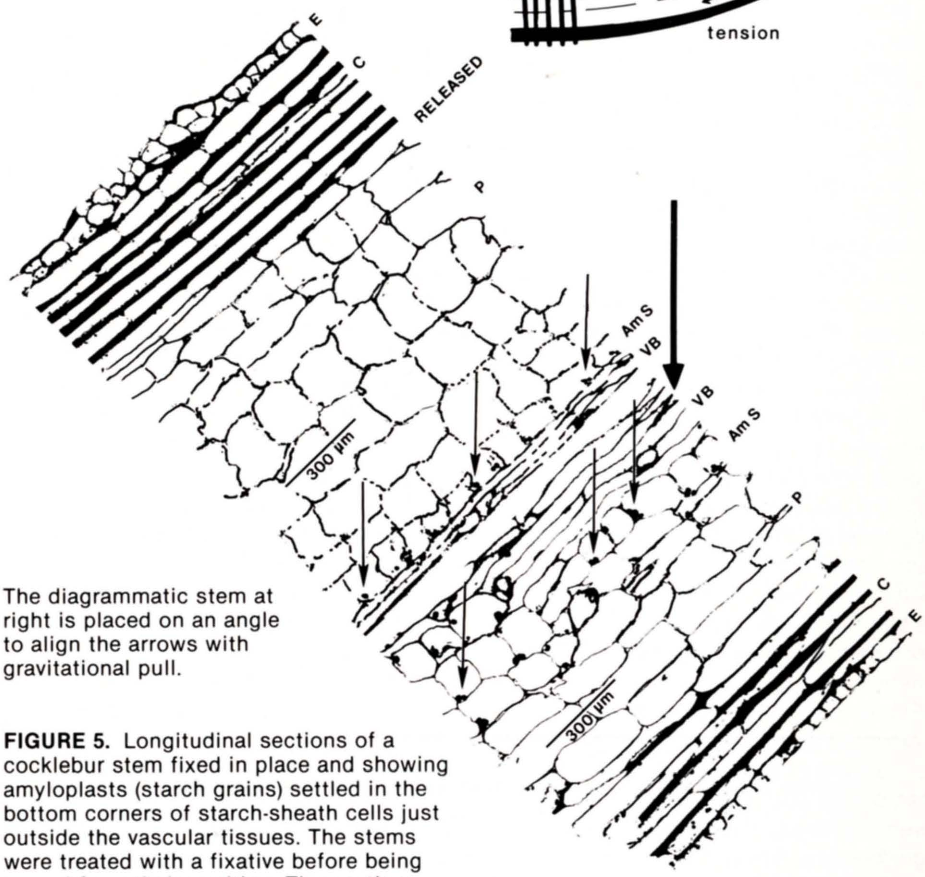
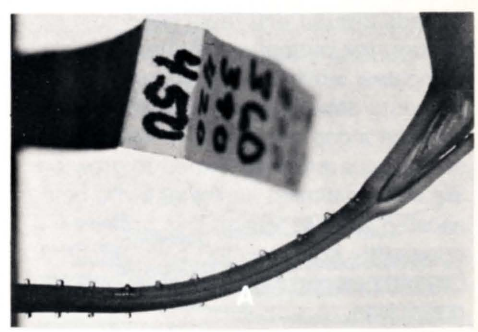



**FIGURE 2.** Forces within a horizontal object held at one end. Top drawing: The weight of such an object causes compression on the bottom and stretching or tension on the top. Bottom drawing: If the object is elastically bent upward as in the experiment discussed in the text, the top is compressed and the bottom is stretched.




The diagrammatic stem at right is placed on an angle to align the arrows with gravitational pull.

**FIGURE 5.** Longitudinal sections of a cocklebur stem fixed in place and showing amyloplasts (starch grains) settled in the bottom corners of starch-sheath cells just outside the vascular tissues. The stems were treated with a fixative before being moved from their position. The sections were cut from a portion of the bending stem. Arrows all point downward.
(Micrographs by Julianne Sliwinski.)



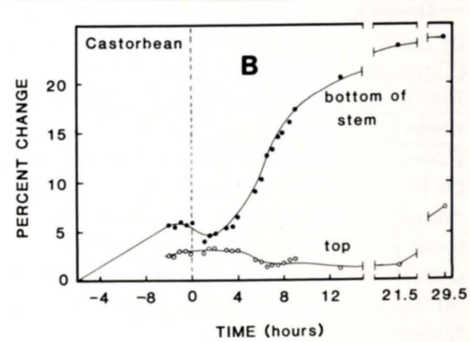




**FIGURE 7.** Change in dimensions of the top and bottom of a castorbean stem shown as a function of time during gravitropic bending. **A.** Sample photograph of the stem taken during the experiment. Minute glass beads were attached to the stem with stopcock grease, photographs were taken at intervals, and distances on the photographs between four sets of beads in the bending region were totalled to give the results shown in the graph (**B**). When a stem is laid on its side, its weight causes it to bend downward slightly, accounting for the initial shrinkage after time zero on the bottom of the stem. Note that growth on the top ceases for 21.5 hours after which growth begins again. The drop in the curve for the top may indicate some shrinkage (beginning at about 4 hours).
(Experiment of Wesley Mueller and Chauncy Harris.)

stems laid on their sides increases compared to vertical control plants, but growth on the top of the stems comes to an almost complete stop soon after the stems are laid on their side. The castorbean changes were so small we can not say exactly when they occur, but the curves in Figure 7B suggest that stem growth on top stops almost instantaneously. There may even be some compression of the cells. This may be indicated by the drop in the curve for the top (beginning at about 4 hours). (Again, studies of this type were done by early workers, and recent studies have been described by Richard Firn and John Digby in England.)

We have studied plants while they were restrained and others when they were released after being restrained for several hours (Figure 8). A system of stereophotography was used, in which two cameras were placed above the plant, and two simultaneous photographs were taken. By analyzing the two negatives, we obtain measurements of stem growth in three dimensions.

Figure 8 shows that stems continue to elongate as they are restrained. Since the restraint prevents bending, growth rates on top and on bottom are essentially the same (except for the slight bending that occurs despite the restraint of the threads). When the threads are cut and rapid bending occurs, the bottom of the stem elongates, while the top shrinks. Amounts depend on species and location along the stem. Restrained stems apparently continued to grow on the bottom almost as if they were being allowed to bend freely. This growth apparently stretches top cells, which ceased growing when the stem was laid on its side.

These observations are substantiated by examining the cells themselves (Figure 9). Cells on the bottom of the restrained stem are not only longer than those on top of a free-bending stem, but they are also thicker in diameter. Cells on the top of the restrained stem are nearly as long as those on the bottom (nearly, because some bending does occur). They are also thinner than cells on the bottom; this is especially noticeable in the micrographs.

Upon stem release, cells on the bottom get longer and thinner and cells on top get shorter and thicker. Figure 10 shows some values obtained by measuring dimensions on photomicrographs. Each set of data represents an individual plant, so it is not possible to rigorously compare data before and after release. (Note the variability along the stem shown in Figure 8.) Nevertheless, rough calculations suggest that cell volumes do not change upon release from restraint and during the sudden bending. As cells on the bottom get longer, they also get thinner, so their volumes remain essentially the same. As cells on top get shorter, they also get thicker, which conserves volume. It is not difficult to imagine that cells on top simply stop growing (taking up water) as soon as the stem is laid on its side. Thus, they are simply stretched by the continued growth of the bottom cells; upon release they return to their approximate condition at the time the stem was laid on its side. It is much more difficult, however, to imagine how and why the cells on the bottom should stretch upon release to lengths that they had never experienced, while simultaneously shrinking in diameter. This has led to much pondering about the mechanisms of plant-cell growth.

## HOW DO STEM CELLS GROW?

The current theory of plant-cell growth has two components:

First, growing cells are continually taking up water from their surroundings by osmosis. Dissolved materials (solutes) in the cells lower the water potential, leading to diffusion of water molecules through the cell membranes and into the cells. This movement of water into cells accounts for *pressure* against the restraining *cell walls* (made of cellulose and other materials; not to be confused with the cell membranes). If the cell is *not* growing, pressure in the cell raises the water potential until it is equal to that of the water in the pores of the surrounding cell wall. With that equilibrium, net osmotic uptake of water ceases.

Second, in the region of the stem where growth is taking place, a growth hormone called auxin (indoleacetic acid: IAA) loosens the plant cell wall. Apparently this occurs as the auxin causes the cell to secrete acid (hydrogen ions) out through the membrane and into the wall. Increasing acidity within the wall, in some way allows the fibers of cellulose (microfibrils) to slide by each other. The wall, then, can stretch *plastically*, and this is *growth*. (If the stretching were *elastic*, as on the top of a restrained stem laid on its side, the cell would go back to its original shape when the stretching force was removed.)

The important point is that loosening of the cell wall reduces the pressure inside. This reduces the water potential inside below that of the surrounding water (in pores of the cell walls) so water enters osmotically. According to this classical theory, which has much evidence to support it, osmosis occurs in growing plant cells because their walls loosen, reducing the pressure and lowering the water potential.

Note that, as cells grow by taking up water, the growth is *directional*. The cells don't simply blow up in all directions like a balloon. Rather, they maintain approximately the same diameter, but they *elongate*.

It has been difficult for us to reconcile our studies on the mechanics of stem bending with this theory of stem-cell growth. When a stem is restricted to a horizontal position, growth apparently occurs on the bottom of the stem, but this is where pressure is continually *increasing* (Figure 11). The theory just described holds that growth occurs as pressure in the cells *decreases* in response to wall loosening.

On top, the cells are being stretched, which, one might imagine, would reduce the pressure inside. Yet growth virtually stops in those cells. In walls of top cells, wall loosening apparently ceases and walls become tight; therefore, as the cells are stretched by growth of the bottom cells, the stretching is elastic. The cells thus return to almost their original size and shape after release from restraint.

Only data on the pressures and other factors that are involved can help us reconcile our observations with the theory of cell growth.

## MEASURING FORCES AND CALCULATING PRESSURE

With the help of P. Thomas Blotter in the Department of Mechanical Engineering at Utah State University, we have measured some of the forces that are developed when stems are restrained in the horizontal position (Figure 12). We can plot the developing forces as a function of time, and we can also release different sets of plants at different times and measure the degree of bending immediately after release. As Figure 12 shows, forces stop increasing when maximum bending after release is achieved.

Since many plants are required to measure the extent of bending as a function of time of release, one of us (WJM) measured the degree of bending upon release and then forcibly straightened the plant out and restrained it again. The next time the plant was released, it showed more bending, as much as other plants released at that time but not previously. That is, the changes that occur upon release are completely reversible. Presumably, when the stem is straightened after it has been allowed to bend, cells on the top are again stretched and made narrower while cells on the bottom are compressed and made thicker, conserving volume in both cases. After the plants have been restrained following release, changes that were occurring before release continue: Cells on the bottom continue to grow, while growth of those on top remains halted.

Using principles of engineering and having measured the forces developed by a restrained stem, it was possible to compute approximate values for the pressures developed on the bottom of a restrained stem and the tensions that develop on top (Figure 12). It is possible that the maximum pressures that can develop on the bottom of a horizontally restrained stem are approximately equal to the maximum pressures that can be developed within cells as they take up water osmotically against the restriction imposed by the cell walls. If this is the case, then wall loosening will lower the water potential inside the cells even if the cells are being compressed

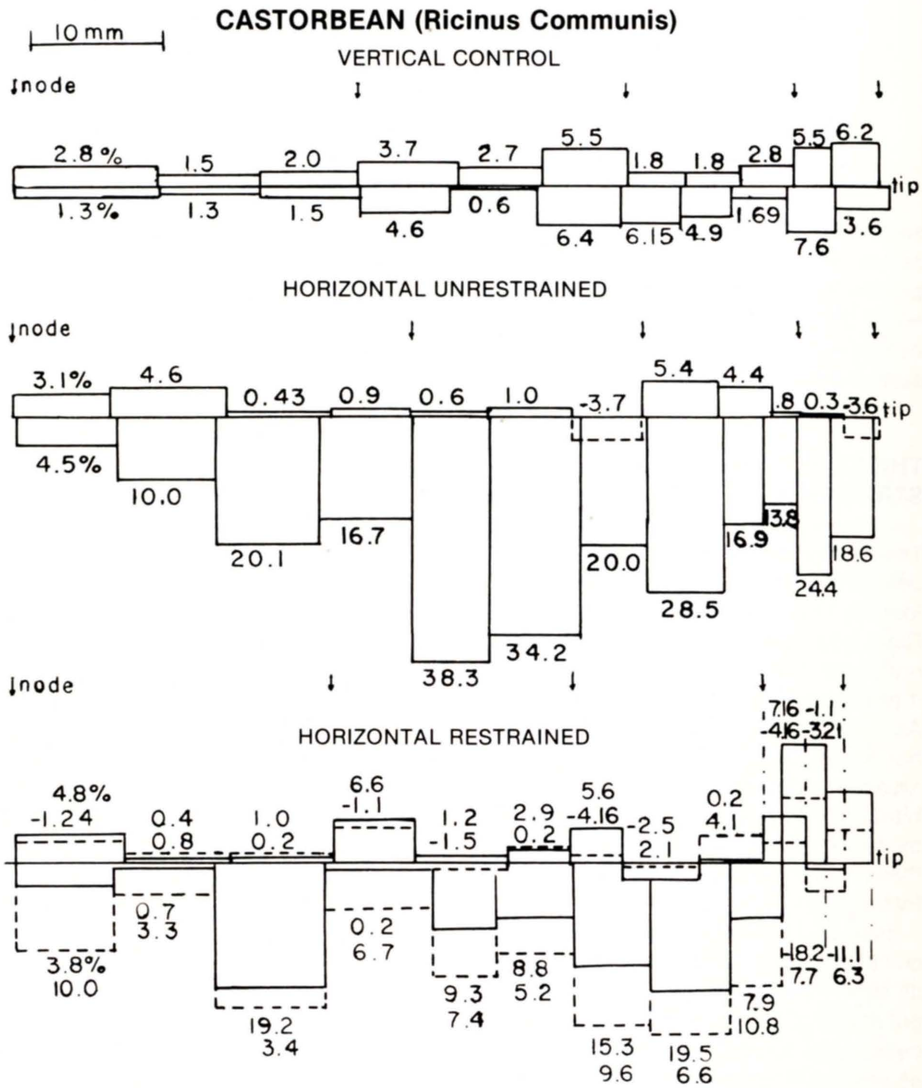



**FIGURE 8.** Three graphs showing the percent growth along the top and bottom of stems over a 48-hour period. Measurements were taken between India-ink dots on the stems of castorbean plants using a system of stereophotogrammetry. The bars indicate changes in length; figures are percentages. The top graph shows the growth of the normal vertical plant. The middle graph shows how the stem stops growing on the top and increases in growth rate on the bottom when it is placed in the horizontal position. The bottom graph shows the change in growth from the time the plants were restrained until the end, just before the plants were released (solid lines). The dotted lines show the change in length after release. Note that the bottom increased in length while the top shrunk a bit. (Data of Wesley Mueller.)

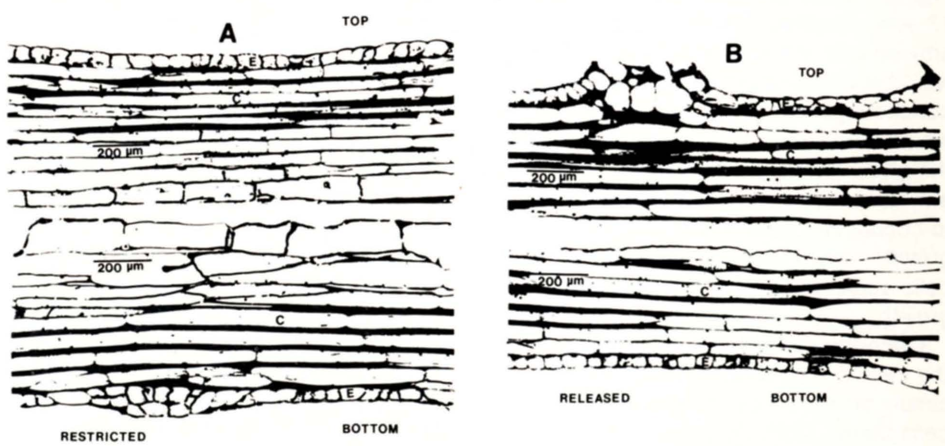



**FIGURE 9.** Cocklebur stems in longitudinal section. **A.** Stem that was fixed in the restricted condition. Note how the cells in the top of the stem are narrowly stretched in comparison with the cells in the bottom, which are bulging. **B.** Stem that had been restricted and then released.

somewhat from the outside. Perhaps the curves in Figure 11 level off when the pressures that develop *outside* the cells equal the pressures developed by osmosis *inside*. We are presently testing such ideas.

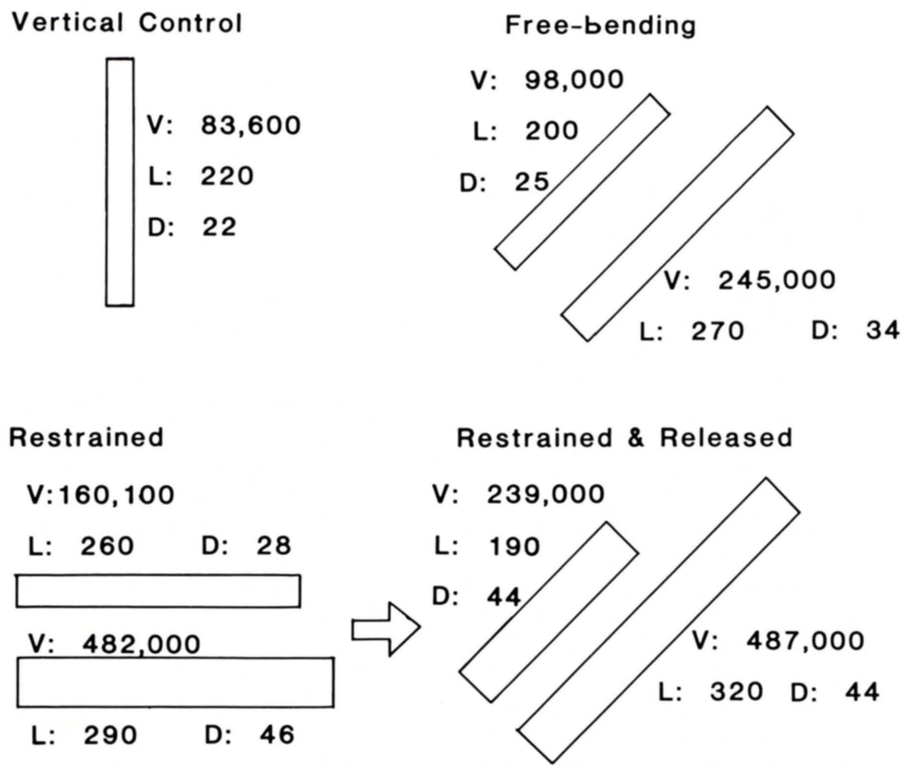



**FIGURE 10.** Diagrammatic representation of changes in cell dimensions for the four conditions shown. Volume was calculated using lengths and diameters measured from photomicrographs. Rectangles are drawn to scale and represent cells; angles shown are approximately those of the stems at the time of fixing and the point of sampling. (Data of Julianne Sliwinski.)

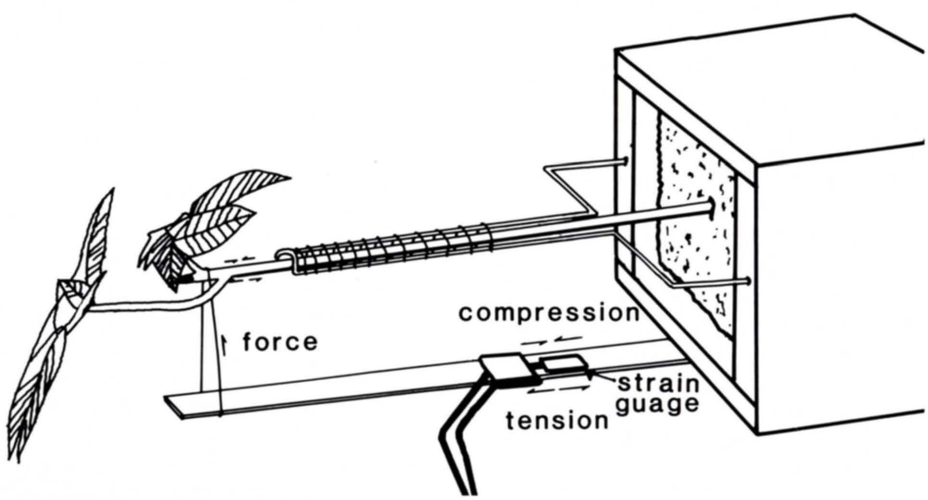



**FIGURE 11.** Use of strain gauges to measure the forces that develop in a restrained horizontal plant stem over time. As the force increases in the cells on the bottom of the stem, it pulls against the metal bar, causing it to bend slightly. The resultant strain on the bar is measured with the attached strain gauge.

## THE ROLE OF CELL-WALL STRUCTURE

The experiments we have been describing answer a few questions and identify new ones in need of answers. Right now, it appears that a better understanding of cell-wall structure, how it forms and how it functions, is crucial. As noted already, the cells on top of a horizontal stem apparently stop growing as soon as the stem is turned to the horizontal position. Recently published evidence shows that acid secretion into these cell walls stops (Mulkey and Evans 1981).

How do these top cells "know" so quickly that the stem has been laid on its side? The direction of change in gravitational forces is the same for *all* cells in the stem, those on the bottom as well as those on the top, yet regardless of the direction in which the plant is tipped to place it on its side, the cells on top seem to immediately sense that they are on top and should stop growing. A possibility occurred to one of us (JES), based upon the location of the starch sheath in leafy stems. As you can see from the photomicrographs of Figure 4 and from the drawing in Figure 13, when a stem is laid on its side, the amyloplasts in the starch sheath on top would fall toward cell walls that contact conducting cells; those on the bottom would fall toward growing cortex cells in the stem. Perhaps contact of amyloplasts with sides of cells adjacent to conducting cells effectively halts growth—while contact with sides of cells adjacent to cortex cells promotes growth.

Once the stem is laid on its side and the cells on top stop growing, they are simply stretched by the growth of the cells below. Cells on the bottom continue to elongate, and because they are doing so (in restricted plants) against the tensile strength of the cells on top, they become thicker as they fill osmotically with water. Why do they become longer and narrower upon release, achieving dimensions they have never experienced, but that are normal for the bottom cells in a stem that has bent upward away from gravity? Why don't they simply expand in all directions like a balloon, and why should they change their dimensions upon release?

Clearly, answers to those questions lie in an understanding of the orientation and arrangement of the cellulose microfibrils in the cell walls (Figure 14). During restriction, the microfibrils in the bottom cells must be laid down in such a way that the cells will naturally assume a longer, narrower set of dimensions upon release. Here is where the secret must lie, and this is where some of our study is to be concentrated.

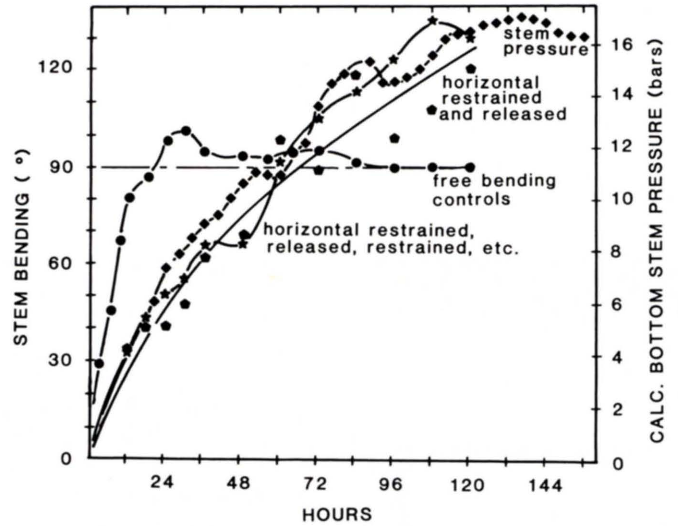



**FIGURE 12.** Graph showing stem bending (degrees) and calculated stem pressure (bars) with various treatments over time. The circles are the free-bending control plants. They were laid on their sides, allowed to bend in response to gravity, and measured at intervals. The pentagons show the bending of plants when released from the restrained horizontal position; each point represents a separate set of plants. The stars show the average bending of plants that were restrained in the horizontal position, released to measure the angle to which they bend, and then straightened and again restrained until the next time of measurement; all stars represent the same set of plants. The diamonds show the calculated stem pressure (in bars) for horizontal plants. (Data of Wesley Mueller and P. Thomas Blotter.)

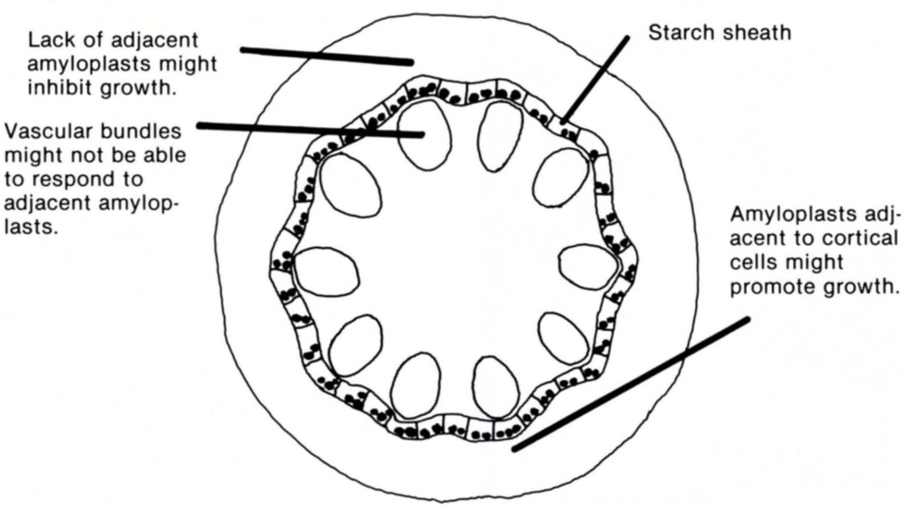



**FIGURE 13.** Diagram of a stem in cross section showing the settling of starch grains when the stem is placed on its side.


ABOUT THE AUTHORS

Frank B. Salisbury is a native Utahn with bachelor's and master's degrees from the University of Utah and a doctoral degree from the California Institute of Technology. After a year at Pomona College and eleven years at Colorado State University, he came to Utah State University in 1966 as Professor of Plant Physiology and Head of the Plant Science Department. He resigned as Department Head in 1970. His research has been concerned with the physiology of flower initiation, ecology of alpine plants, responses of plants to ultraviolet light and to freezing temperatures, and now with plant responses to gravity.

Julianne Sliwinski, after working as a technician in biochemistry and electron microscopy, came to Utah State University, where she finished her doctoral degree studying cellular changes during gravitropic stem bending. After these studies as a postdoctoral fellow with Dr. Salisbury for half a year, she is now working as a postdoctoral fellow with Dr. Donald R. Geiger at the University of Dayton in Ohio.

Wesley J. Mueller majored in zoology at Brigham Young University for his bachelor of science degree in 1977. His master of science degree was completed in 1981 based on research into the changes that take place in the dimensions of stems bending in response to gravity. His doctoral research is a continuation of his studies on the mechanics of stem bending.

Chauncy S. Harris earned his bachelor's and master's degrees in botany from Old Dominion University in Norfolk, Virginia, where he researched parasitic angiosperms and their relationship with and effects on their host plants. Mr. Harris' PhD research at USU is on mechanical stress and weightlessness in plants, specifically separating the effects of each in clinostated plants and the role that callose may play in such effects.


BIBLIOGRAPHY


Audus, L. J. 1962. The mechanism of the perception of gravity by plants. Symp. Soc. Exp. Biol. 16:197-226. (Noted early work on gravity detection via tension/compression caused by stem weight.)

Bateson, A. and F. Darwin. 1888. On a method of studying geotropism. Ann. Bot. 2:65-68.

Beyer, E. M. 1979. Effect of silver ion, carbon dioxide, and oxygen on ethylene action and metabolism. Plant Physiol. 63:169-173.

Chadwick, A. V., S. P. Burg. 1970. Regulation of root growth by auxin-ethylene interaction. Plant Physiol. 45:192-200.

Digby, J. and R. D. Firn. 1979. An analysis of the changes in growth rate occurring during the initial stages of geocurvature in shoots. Plant Cell Environment 2:145-148.

Firn, R. D. and J. Digby. 1980. The establishment of tropic curvatures in plants. Ann. Rev. Plant Physiol. 31:131-148.

Franssen, J. M., S. A. Cooke, J. Digby, and R. D. Firn. 1981. Measurement of differential growth causing phototropic curvature of coleoptiles and hypocotyls. Z. Pflanzenphysiol. 103:207-216.

Juniper, B. E. 1976. Geotropism. Ann. Rev. Plant Physiol. 27:385-406.

Lieberman, M. 1979. Biosynthesis and action of ethylene. Ann. Rev. Plant Physiol. 30:533-591.

Mulkey, T. J. and M. L. Evans. 1981. Geotropism in corn roots: evidence for its mediation by differential acid efflux. Science 212:70-71.

Salisbury, F. B., R. M. Wheeler, J. E. Sliwinski, and W. J. Mueller. 1982. Plants, Gravity, and Mechanical Stresses. Utah Science 43:14-21.

Takeda, K. and H. Shibaoka. 1981. Changes in microfibril arrangement on the inner surface of the epidermal cell walls in the epicotyl of *Vigna angularis* Ohwi et Ohashi during cell growth. Planta 151:385-392.

Volkmann, D. and A. Sievers. 1979. Graviperception in multicellular organs. In: W. Haupt, M. E. Feinleib (eds.) Encyclopedia of Plant Physiology. New Series, Vol. 7, Springer-Verlag, Heidelberg, pp. 573-600.

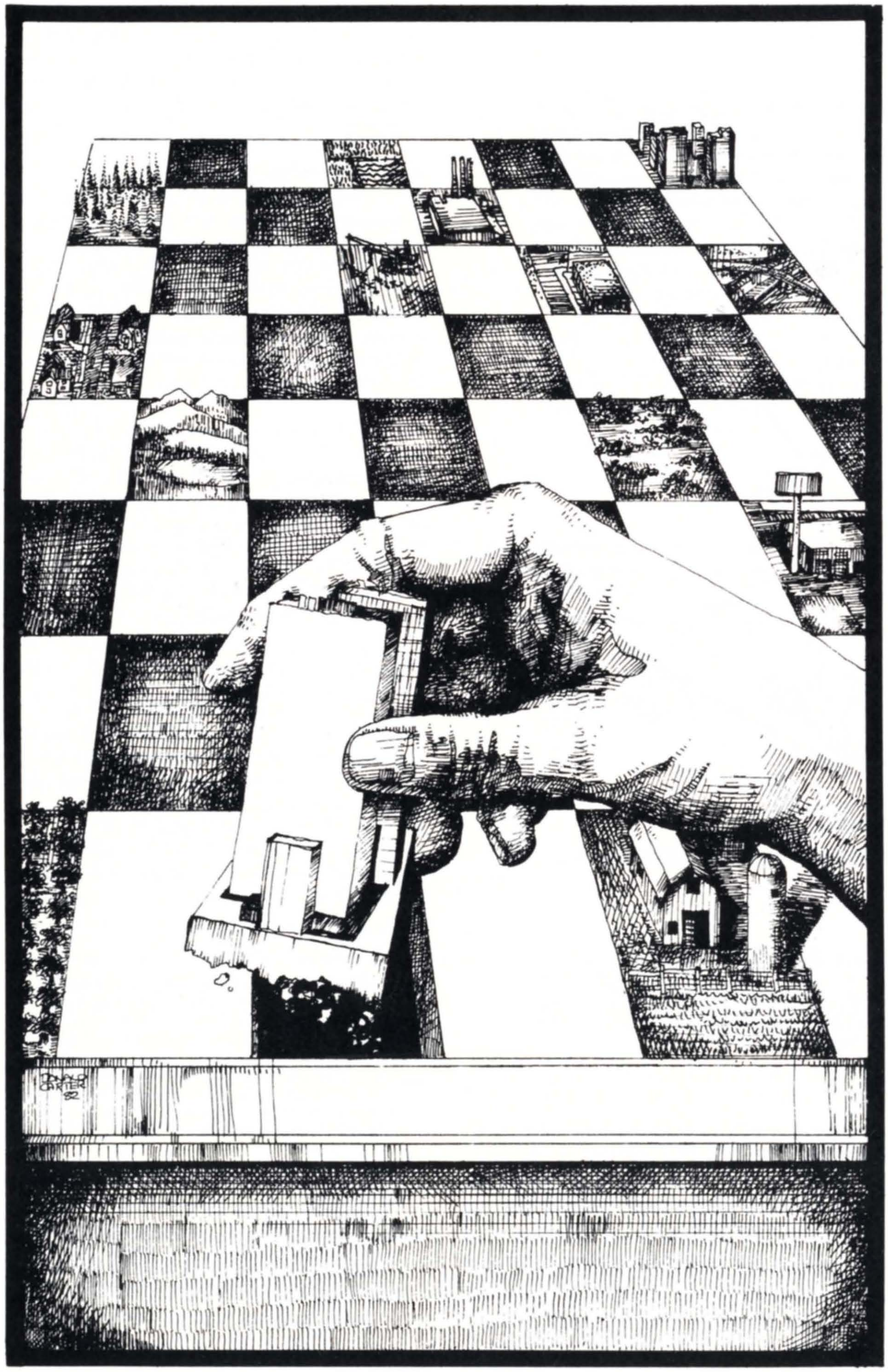
Wheeler, R. M. and F. B. Salisbury. 1981. Gravitropism in higher plant shoots. I. A role for ethylene. Plant Physiol. 67:686-690.

Wilkins, M. B. 1979. Growth-control mechanisms in gravitropism. In: W. Haupt, M. E. Feinleib, eds. Encyclopedia of Plant Physiology, New Series, Vol. 7, Springer-Verlag, Heidelberg, pp. 601-626.

W. CRIS LEWIS and ERIC MARNELL

# AGRICULTURAL LAND USE

## AND LAND-USE CONTROL



THE FUNDAMENTAL GOAL of any economic system is to allocate resources (land, labor, and capital) to meet the objectives of society. Because it must continually reallocate these resources, an economic system is extremely dynamic, with literally millions of economic decisions being made daily. Therefore, we should expect significant changes in resource reallocation over time periods of a year or more. Some of these changes are obvious to all; others are apparent only to those directly involved.

For example, the demand for labor in the blast furnace industry has declined sharply. In 1970, 563,500 workers were employed in that sector; by 1980, employment had declined to 429,300. This is not a widely known fact, but to those who lost their jobs and for the owners and stockholders who saw the value of their assets decline, the memories are very real. Consider these other changes in employment:

| Industry | Employment (000) 1970 | 1980 | Change (000) |
|---|---|---|---|
| Oil & gas extraction | 272.4 | 552.0 | + 279.6 |
| Elect. computing equip. | 196.5 | 350.2 | + 153.7 |
| Motor vehicles & equip. | 874.9 | 762.6 | -112.3 |

Our social system is sensitive to the human suffering associated with unemployment. Realities dictate, however, that some industries decline over time, releasing resources for employment elsewhere, while others expand, creating jobs and requiring new capital investment. The employment dislocations are eased by such mechanisms as unemployment insurance, lump sum settlements at the time of job loss, relocation assistance, and job retraining.

Such resource allocation usually proceeds with little public awareness except for those directly affected. Land-use change, however, is quite visible to all in an area and can be very disturbing to some. Certainly, some of the most heated "battles" waged in our city and county buildings revolve around proposed land-use changes. A proposal to change zoning laws to allow multiple-family structures or retail activity in a neighborhood dominated by single-family

**Land-use changes are a manifestation of the economic system at work and should be viewed positively.**

homes is sure to rouse protests. Changes involving a shift of agricultural land to housing or other nonagricultural use also are worrisome to some citizens, who may protest the proposed change at public hearings and council/commission meetings. Fundamentally, of course, these land-use changes are simply a manifestation of the economic system at work and, in the absence of strong evidence to the contrary, should be viewed positively.

Land-use change has been both rapid and highly visible on the bench area of Davis County, where orchard and other agricultural production has been giving way to residential development. Although the pace of housing development in that area has slowed in the past 18 months, some view this conversion of farmland with alarm. We see it as an indication that the market is reallocating land to a use with greater social value.

It is well-known that the past ten to fifteen years were ones of rapid urban development in Davis and Salt Lake Counties. What is not well-known is that total acreage in orchards actually increased during this period in both counties! As shown in Table 1, total orchard acres increased by 14 percent to 556 acres in Davis County and by 169 percent to 130 acres in Salt Lake County. Thus, while houses, schools, and churches were replacing orchards on some land, new orchards were being planted on other land.

In fact, of the nineteen counties in Utah with any significant orchard activity, land devoted thereto increased in all but two (Uintah and Weber), and in those, the total net reduction was only 28 acres. Statewide, orchard acreage increased by more than 2,700 acres or 31 percent. Casual observation clearly is not adequate when assessing resource shifts. In this case, it would suggest declining orchard activity when just the opposite is true. Utah County, among the most urbanized and faster "urbanizing" areas in the state, has more than 6,000 acres in orchards and added 1,228 acres between 1969 and 1978, while population was growing by 58 percent. Furthermore, urban areas account for such a miniscule part of total land use in the nation that there is little reason to expect a conflict between urban growth and agricultural production. In fact, one-sixth of the nation's cropland is in counties that are classified as metropolitan areas.

Indeed, because urban areas are direct markets for many products (e.g., fruits, vegetables, milk, cheese, etc.), we should think of agriculture as part of the industrial base of our urban areas. While retail trade and finance are concentrated in the downtown area or in suburban shopping centers, the agricultural industry, requiring large quantities of land and relatively little labor, is located on the cheapest land at the periphery of the urban area. The expansion of one urban activity (e.g., housing, retail trade, etc.) often results in a change of location for another (e.g., agriculture). As long as no participant is forced to move, we can usually be sure that such relocations reflect a calculated response to economic incentives.

## AGRICULTURAL LAND: UTAH AND NATIONAL TRENDS

During 1969-1978, total cropland in Utah was expanded by more than 110,000 acres, an increase of 5.8 percent over the 1969 base. Nineteen of the 29 counties recorded an increase in cropland; the largest changes being recorded in San Juan County (+45,401), Millard County (+36,337), Box Elder County (-28,999), and Iron County (+9,739). These data are summarized in Table 2.

This expansion in the cropland base of the state is inconsistent with the notion that the land base is being threatened by urban-industrial growth. Clearly, this period has been characterized by greater population and nonagricultural employment growth than any other ten-year period in Utah history. Population growth in Utah over the intercensal period 1970-80 was almost 38 percent, or 3.3 percent per year, one of the most rapid growth rates recorded by any state. During this period, more than 400,000 new residents were added to the state's population base. Seven counties recorded population growth in excess of 50 percent. These include Emery, Garfield, Kane, Summit, Uintah, Utah, and Washington.

The Utah experience is a manifestation of the dynamic resource reallocation process described above. The land base for agriculture was contracting in some counties while expanding in others. In the aggregate, this land base was significantly higher at the end of the period than at the beginning. It is not clear that these trends provide any basis for concern about the future supply of agricultural products.

Furthermore, there is no clear relationship between population growth and the agricultural land base. Some argue that the population growth necessarily implies reductions in cropland as houses, roads, and commercial developments are placed on what was agricultural land. Houses certainly have been built on agricultural land, but the farmland removed from production has been replaced by land in other areas. Clearly, Salt Lake City experienced a tremendous increase in population and its agricultural land declined by more than 20,000 acres. Utah County, however, experienced a large population increase (more than 80,000) while actually recording a small increase in cropland. Of the twelve counties reporting above-average population growth rates for the 1970-1980 period (i.e., a growth rate in excess of 37.9 percent), six recorded increases in total cropland. It is our position that the general economic conditions in agriculture, especially commodity prices, are much more important in determining the size of the cropland base than are changes in urban population.

As shown in Table 3, the cropland base in the United States has been roughly the same since 1910. The 1978 level of 361 million acres is about 10 percent higher than in 1910 but somewhat lower than in the 1930 period. The recent national trends have been consistent with those recorded in Utah. Cropland used for crops expanded by approximately 28 million acres from 1969 to 1978, an increase of 8.4 percent. Of course, the nation's urban areas also expanded during this period.

Agricultural commodity prices are more important in determining cropland base than are changes in urban population.

## PROJECTING THE FUTURE

Projections of economic or other activity are notoriously poor. Those who would have us believe that we are running out of land point to trends that, when extended far enough, result in a zero land base or at least an "inadequate" land base at some future date. Clearly, the future cannot be assessed on the basis of an extrapolation of a past trend. To show how ludicrous the process is, historic data on agricultural land and labor each were regressed on time, and then the time trend extrapolated until the dependent variables reached the zero level. This "exercise" is summarized below. The estimated equation for land is:

$$L = 476.02 - 0.25T$$

where L is agricultural land (in millions of acres); and T is a time index (i.e., T = 1 for 1930, T = 2 for 1931, etc.). This equation suggests a long-term trend reduction of about 250,000 acres per year in the agricultural land; recall the total agricultural land base is almost 500 million acres. If this trend continued, the U.S. would run out of farmland, but not for 2000 years! The trend equation for farm labor is:

$$LF = 13{,}070 - 191.6T$$

where LF is the agricultural labor force (in thousands); and T is the same time index used above. The trend, well-known to the observer of the agricultural scene, has been a reduction in agricultural labor of about 191,000 per year. This trend, if projected, would result in total elimination of agricultural workers by 1998! We come to the ridiculous conclusion that by that date there will be no workers on some 500 million acres of land.

An example of the fallacious use of past trends is found in the energy field. Prior to the rapid increase in energy prices in the early 1970s, energy use per capita in the United States was increasing at a rate of 3 or 4 percent per year. This was largely the result of declining real (i.e., adjusted for inflation) prices. The projections of that time had the United States consuming vast quantities of energy products, especially oil, by 1980 and 1990, and, in fact, eliminating known reserves prior to the end of the century. Economic conditions changed dramatically; significantly higher prices resulted in the conservation of existing supplies and a considerable increase in exploration activity. As a result, oil production in the United States has actually increased, reversing a 20-year decline. U.S. consumption is now some 20 percent below its peak in 1978-1979, known reserves have been expanded, and, at this date, the OPEC oil-producing organization is on the verge of collapse—their prices simply cannot be maintained in an environment of expanding production and declining demand.

There is an important point in here for those of us concerned about the future of the agricultural land base. Changes in demand for farm products are immediately signaled to producers via the price system. These signals are transformed into changes in the level and mix of production and, of course, the amount of land devoted to agricultural use. Those who operate directly in that market are knowledgable about these trends and developments and can usually respond quickly. Indeed, the land-use changes observed in the last ten years show a rapid adjustment to changes in market signals. Furthermore, this group is not shortsighted; they are not interested in maximizing this year's profits. There is every reason to expect them to want to maximize the present value of all future profits to be earned in their agricultural activities. As a result, they are very interested and aware of long-run changes in demand, potential population increases in various parts of the world, and the rapidly changing production conditions which face them.

American agriculture is, perhaps, the most productive and dynamic economic activity in the world today. It is our position that its members should provide the leadership in meeting current and future demand for agricultural products, and that they are best suited to determine the current and future resource needs of their industry. To be sure, agriculture must compete with other activities for resources, a prime example being housing. We have good reason to believe that it will be able to do so effectively. The problems of Utah agriculture today are not the result of an inadequate land base but of commodity prices that are too low to provide adequate profits to producers. We view this as a short-term phenomenon that is characteristic of a highly competitive and dynamic industry. It is unfortunate that it results in severe dislocations and financial hardships for some agricultural producers.

## PRODUCTIVITY

Productivity in agriculture continues to increase. There is much evidence that the U.S. farm industry is the most productive of any in the world, agricultural or nonagricultural. The period 1969-1979 was one of rapid growth in productivity. Total productivity, a measure of agricultural output per unit of total agricultural input, increased 16.7 percent. Land productivity, over the same interval, increased by almost 23 percent.

Some base their argument for agricultural land preservation laws on the premise that land productivity is leveling off and that the future would see little, if any, further gains. The data simply do not support that hypothesis. Productivity data for 1929-1979 are reported in Table 4. Clearly, there has been no perceptible change in the rate of productivity growth. For total productivity, the average annual rate for 1969-1979 (1.65 percent) was lower than in the period 1939-1959 but higher than in the 1929-1939 and 1959-1969 decades. The increase in land productivity has been very stable at about 2.1 percent per year for 30 years.

## SUMMARY

Of the total land area in the United States (approximately 2.3 billion acres), about 8 percent falls into the special-use category. These uses include urban

Utah's cropland base has grown significantly in 10 years.

transportation areas, federal and state areas used for recreation and wildlife, military bases, farmsteads, farmroads and lanes, and miscellaneous other uses. So-called built-up areas, including cities and urban road networks, at most, account for about 3 percent of the total land area. This is miniscule, and the amount of land devoted to new urban activities over the past ten years of rapid urban growth has been, of course, even smaller. There is good reason to think that much of the expansion of urban areas in the United States is over. The overall rate of population growth has slowed, and the environmental and other problems of large urban areas have become more acute, making some of them less desirable places. Higher energy prices have simultaneously provided an incentive for locations closer to employment centers, smaller homes and lots, etc. We probably will not see the rapid urbanization trends in the next twenty years that we saw in the past twenty years.

But what if the total land allocated to urban areas doubled from 3 percent of the total to 6 percent of the total? Would this make a difference in the ability of agriculture to meet the demand for food? Probably not. The ability to feed the world's population will ultimately depend on the provision of adequate incentives for food production. Policies designed to inhibit the movement of land or any other resource in response to economic incentives will have a net negative impact not only on those directly effected by the control, but for all of us.

## ASSESSING THE FUTURE

Too much of "research" on agricultural land-use conversion begins with the premise that protecting or preserving agricultural farmland is, in some sense, necessary and of general benefit. As scientists, we find this quite disconcerting. In our view, the research should progress in the following way:

A comprehensive approach should be taken, wherein the total benefits and costs of land-use conversion are assessed. Certainly, the effects of land-use regulation, requiring that certain lands be kept in agricultural use, have

**TABLE 1. LAND IN ORCHARDS IN SELECTED UTAH COUNTIES, 1969-1978**

| County | 1969 | 1978 | Change (acres) | Change (%) |
|---|---|---|---|---|
| Box Elder | 1,816 | 2,288 | +472 | +26.0 |
| Cache | 160 | 206 | +46 | +28.8 |
| Carbon | 7 | 18 | +11 | +157.1 |
| Davis | 487 | 556 | +69 | +14.2 |
| Duchesne | 15 | 32 | 17 | 113.3 |
| Emery | 37 | 107 | 70 | 189.2 |
| Garfield | 9 | 36 | 27 | 300.0 |
| Grand | 55 | 67 | 12 | 21.8 |
| Iron | 9 | 20 | 11 | 122.2 |
| Kane | 39 | 53 | 14 | 35.9 |
| Millard | 4 | 13 | 9 | 225.0 |
| Salt Lake | 189 | 319 | 130 | 68.8 |
| San Juan | 2 | 30 | 28 | 1,400.0 |
| Tooele | 1 | 22 | 21 | 2,100.0 |
| Uintah | 15 | 12 | -3 | -20.0 |
| Utah | 5,016 | 6,244 | +1,228 | 24.5 |
| Washington | 163 | 594 | 431 | 264.4 |
| Wayne | 45 | 51 | 6 | 13.3 |
| Weber | 579 | 554 | -25 | -4.3 |
| 19-County Total | 8,648 | 11,361 | +2,713 | +31.4 |

SOURCE: U.S. Bureau of the Census. 1981. *Census of Agriculture, 1979.* Washington, D.C.: U.S. Government Printing Office.

**TABLE 2. CROPLAND AND POPULATION IN UTAH, 1969-1980**

| | Cropland | | | | Population 1970-80 | |
|---|---|---|---|---|---|---|
| | Total | | | | | |
| County | 1969 | 1978 | Change | Percent Change | Change | Percent Change |
| | acres | | | | | |
| Beaver | 29,917 | 37,769 | +7,852 | +26.2 | 578 | 15.2 |
| Box Elder | 360,571 | 331,572 | -28,999 | -8.0 | 5,093 | 18.1 |
| Cache | 176,926 | 173,036 | -3,890 | -2.2 | 14,845 | 35.1 |
| Carbon | 14,692 | 16,431 | +1,739 | +11.8 | 6,532 | 41.7 |
| Daggett | 8,106 | 6,967 | -1,139 | -14.1 | 103 | 15.5 |
| Davis | 40,946 | 34,497 | -6,449 | -15.8 | 47,512 | 48.0 |
| Duchesne | 96,035 | 101,246 | +5,211 | +5.4 | 5,266 | 72.1 |
| Emery | 48,344 | 41,472 | -6,872 | -14.2 | 6,314 | 122.9 |
| Garfield | 23,714 | 24,754 | +1,040 | +4.4 | 517 | 16.3 |
| Grand | 3,132 | 4,907 | +1,775 | +56.7 | 1,553 | 23.2 |
| Iron | 65,973 | 75,712 | +9,739 | +14.8 | 5,172 | 42.5 |
| Juab | 77,275 | 67,485 | -9,790 | -12.7 | 956 | 20.9 |
| Kane | 11,215 | 13,805 | +2,590 | +23.1 | 1,603 | 66.2 |
| Millard | 151,319 | 187,656 | +36,337 | +24.0 | 1,982 | 28.4 |
| Morgan | 16,527 | 20,647 | +4,120 | +24.9 | 934 | 23.4 |
| Piute | 15,302 | 17,883 | +2,581 | +16.9 | 165 | 14.2 |
| Rich | 66,550 | 75,126 | +8,576 | +12.9 | 485 | 30.0 |
| Salt Lake | 69,415 | 48,929 | -20,486 | -29.5 | 160,459 | 35.0 |
| San Juan | 91,299 | 136,700 | +45,401 | +49.7 | 2,647 | 27.6 |
| Sanpete | 98,029 | 107,591 | +9,562 | +9.8 | 3,644 | 33.2 |
| Sevier | 52,320 | 50,310 | -2,010 | -3.8 | 4,624 | 45.8 |
| Summit | 38,218 | 36,425 | -1,793 | -4.6 | 4,319 | 73.5 |
| Tooele | 39,643 | 47,150 | +7,507 | +18.9 | 4,488 | 20.8 |
| Uintah | 93,023 | 85,014 | -8,009 | -8.6 | 7,822 | 61.7 |
| Utah | 139,987 | 142,667 | +2,680 | +1.9 | 80,330 | 58.3 |
| Wasatch | 20,116 | 21,146 | +1,030 | +5.1 | 2,660 | 45.4 |
| Washington | 33,650 | 33,445 | -205 | -0.6 | 12,396 | 90.7 |
| Wayne | 17,642 | 21,471 | +3,829 | +21.7 | 428 | 28.9 |
| Weber | 44,690 | 45,032 | +342 | +0.8 | 18,338 | 14.5 |
| State | 1,896,232 | 2,006,856 | 110,613 | +5.8 | 401,764 | 37.9 |

SOURCE: U.S. Department of Commerce, Bureau of the Census. 1980. *1978 Census of Agriculture—Summary and State Data, Vol. 1, Part 51.* Washington, D.C.: U.S. Government Printing Office.

significant economic implications that extend beyond agriculture. The regulations affect the price and availability of housing, the highway and road pattern, and the price and output levels of agricultural commodities. A policy requiring that land be maintained in agricultural use has not been justified on economic grounds. Indeed, the net effect of such a policy may well be lower agricultural land and commodity prices and, ultimately, reduced agricultural production. The argument is beyond the scope of this paper but, essentially, revolves around the need to provide incentives for agricultural production. Requiring that some inputs stay in the agricultural production process is not consistent with that incentive system.

Not only do we argue that social welfare will be maximized by allowing free market allocation of all resources, including land, we submit that there are some fundamental questions relating to individual freedom here. Is it really fair for one group of citizens to deny another the use of his land in whatever way that individual sees fit as long as it does not impair the ability of other parties to enjoy their rights. Frankly, we are unwilling to suggest that any such power be given to us and, therefore, to anyone else. There is a clear alternative for those who would prefer a given land parcel to be maintained in a particular use or changed to some other use—that is, they may pool their resources, buy the land at the market price, and use it as they see fit. The notion that in some way we are running out or will run out of agricultural land is unsubstantiated and cannot justify land-use controls in any event.

Furthermore, who is to say what is more important as between agricultural production, housing, or a myriad of other activities that consume land, such as the production of automobiles, retail trade, or pocket calculators—all are important. Certainly, in most parts of Utah, we might be able to do without the automobile for a short period of time, but would be hard-pressed to survive long without food and housing.

We view the free market process as the optimal way for all to cast their votes in the land-use decision process. All are buyers of food, housing, and a variety of other goods. The dollars we spend are the analog of votes in the polling place, and largely determine the pattern of resource use in the United States. To suggest that a government-appointed board or commission can effectively represent us all in this process is questionable. While we all may have one vote at the polling place, each of us does not have equal influence in actual political decisions. This has been well-documented in other studies. We will take our chances with the market every time. That has worked well for more than 200 years in the United States, and we see no reason for it not to continue to work well for another 200 years.

"The free market process is the optimal way for all to cast their votes for land use."

ABOUT THE AUTHORS

Dr. Lewis is professor of Economics and head of the Economics Department at Utah State University. He is the director of a research program in land economics funded by the Utah Agricultural Experiment Station.

Mr. Marnell is a graduate of the University of Colorado and is a candidate for a Master's degree in the Economics Department.

**TABLE 3. CROPLAND IN THE UNITED STATES, 1910-78**

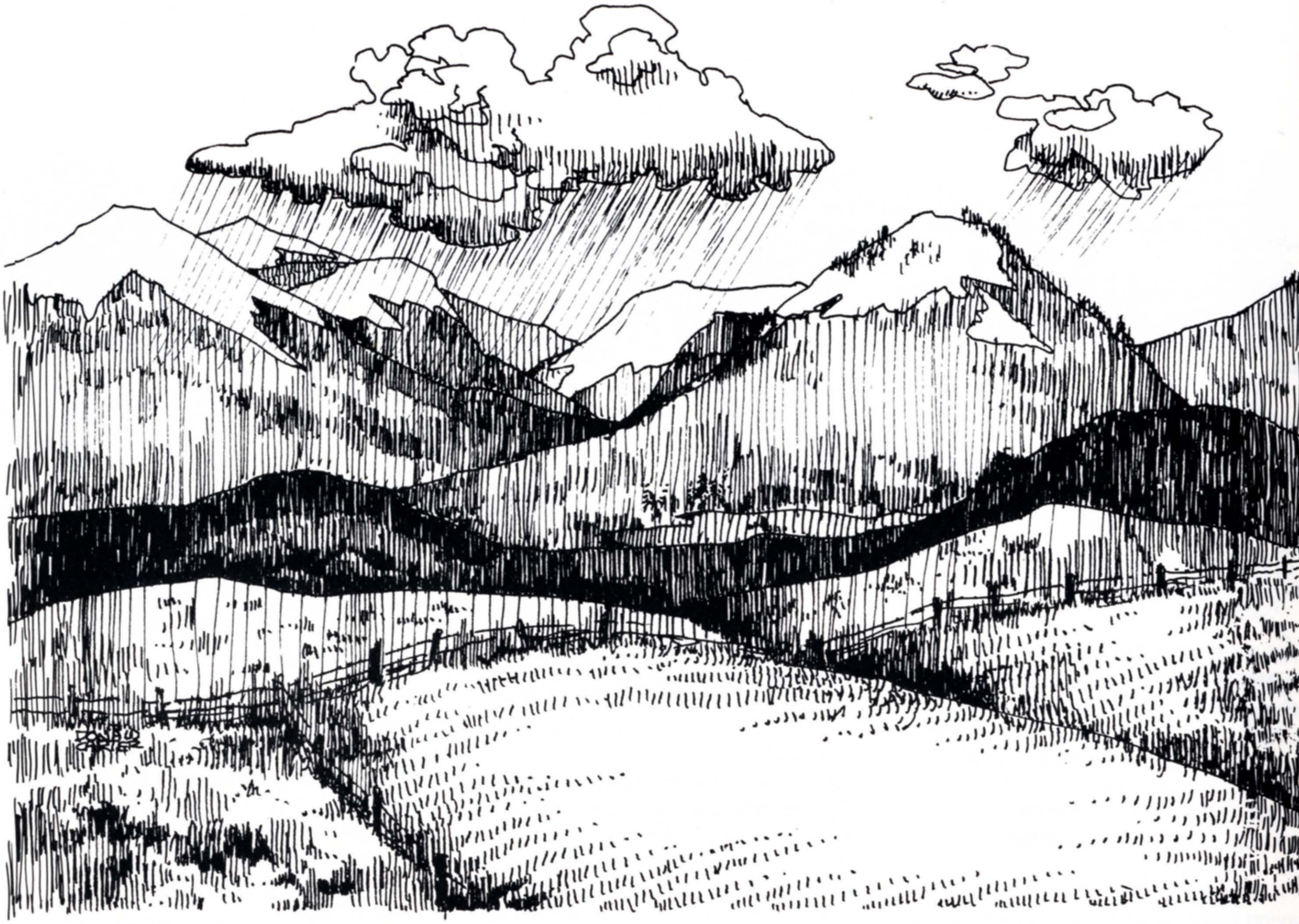
| | Cropland in Crops | | | Total Cropland | | |
|---|---|---|---|---|---|---|
| Year | Total[a] | Change[a] | % Change | Total[a] | Change[a] | % Change |
| 1910 | 320 | — | — | 437 | — | — |
| 1920 | 368 | 48 | 15.0 | 480 | 43 | 9.8 |
| 1930 | 382 | 14 | 3.8 | 480 | — | — |
| 1940 | 368 | −14 | −3.7 | 467 | −13 | −2.7 |
| 1950 | 377 | 9 | 2.4 | 478 | +11 | 2.4 |
| 1959 | 359 | −18 | −4.8 | 458 | −20 | −4.1 |
| 1969 | 333 | −26 | −7.2 | 472 | +14 | 3.1 |
| 1978 | 361 | +28 | +8.4 | 454 | −18 | −3.8 |

SOURCES: U.S. Department of Agriculture. 1981. *Agricultural Statistics, 1980.* Washington, D.C.: U.S. Government Printing Office. Table 602, p. 419; and U.S. Department of Commerce, Bureau of the Census. 1980. *1978 Census of Agriculture—Summary and State Data, Vol. 1, Part 51.* Washington, D.C.: U.S. Government Printing Office. Table 1, p. 1.

**TABLE 4. AGRICULTURAL PRODUCTIVITY: INDEX OF FARM OUTPUT PER UNIT OF INPUT, UNITED STATES,1929-1979**

| | Total[a] | | Land[a] | |
|---|---|---|---|---|
| Year | Index | Annual Percent Change | Index | Annual Percent Change |
| 1929 | 53 | — | — | — |
| 1939 | 59 | 1.08 | — | — |
| 1949 | 73 | 2.15 | 70 | — |
| 1959 | 90 | 2.12 | 86 | 2.08 |
| 1969 | 101 | 1.16 | 106 | 2.11 |
| 1979 | 119 | 1.65 | 130 | 2.06 |

SOURCE: U.S. Department of Agriculture. 1980. *Agricultural Statistics, 1980.* Washington, D.C.: U.S. Government Printing Office.



# moisture: ITS WHERE AND WHEN FACTORS

**WINTER'S SNOW ON THE MOUNTAIN** doesn't necessarily put fall's wheat in the granary. Discrepancies occur because what matters to the life of alfalfa, grass, wheat or any other plant, is the moisture in the soil where it is anchored. And, unfortunately, depending on when and at what rate nature delivers the water, it may be evaporated at the soil surface, or much of it may simply run off, rather than soak in.

Turned on its head, concern about available water (whether stored in the soil or a man-made reservoir), is concern about drought. How to define that phenomenon and, even more important, how to predict its occurrence, are among the questions motivating a long-term, cooperative USU research project. Another is how best to help farmers pre-evaluate each year's crop/water relationships in their own area.

Any measure of drought has to involve data on precipitation; water in streams, lakes and reservoirs; time of year and stage of plant growth; and soil type, temperature and moisture content. The research team (with V. Phillip Rasmussen as leader) is uniting the efforts and individual projects of specialists in those subjects. One goal, previously unattainable because of inadequate technology, is to collect accurate, across-the-state data on soil moisture. The newly available gadgetry can be installed as deep as 20 inches below the soil surface, where it reliably and continuously records moisture conditions.

The researchers will take advantage of already instrumented weather station sites in each of Utah's seven climatic divisions. They will also, however, sample other areas representative of dryland wheat, alfalfa, and range conditions throughout the state. As they thereby optimize the quantity and quality of their data, they will be able to translate precipitation values into soil moisture and begin to answer practical questions about crop and forage production.

Ultimately, 5 years' worth of data will be correlated with observations of seasonal and yearly vegetative productivity. Along the way, the State Climatologist will begin reporting average soil moisture indexes for each of Utah's climatic divisions, as well as other newly calculated values. As the computerized data bank expands, it will be used to generate revised evaluations of soil classifications, and insights into how moisture and temperature values affect plant/soil interactions. If the data collections can be continued over a long enough time, it should be possible to develop computer models that can be used to *predict* periods and places of drought.

On a shorter range basis, the USU researchers will soon be telling people, wherever they live in the state, how many inches of water are being held in their soil, and how to make use of that information.

# Predicting Crop Production

FRANK A. CONDIE

**THE DILEMMA OF THE AMERICAN FARMER—**The increasing spread between total production cost and market price (Table 2)—during the past six years has been nearly disastrous. This was brought about by a combination of factors, among them high production costs, high interest rates, and overproduction.

It is virtually impossible to keep paying more for operating expenses and interest, receiving less for your product, and still stay in business. Farmers, however, seem to do this better than anyone else.

President Reagan has publicly stated that 1982 will be a difficult year for farmers, acknowledging that some will go bankrupt, but asked them to "hang in there." Other farm experts say the same thing.

The costs of labor, fuel, and other expenses have continued to follow a moderate upward spiral (4 percent) during the past two years, while depreciation (cost of equipment) and repairs were escalating at a 15 percent rate. In 1980 and 1981, interest on equipment increased 23 percent; interest on land purchases increased 16 percent. Over the same time, the price of wheat dropped 12 percent from two years ago to \$3.16. It reached a low of \$2.70 (under 10 protein) at some grain elevators this spring. Overproduction last year, coupled with declining exports (which have suffered from previous embargoes), have adversely affected grain markets.

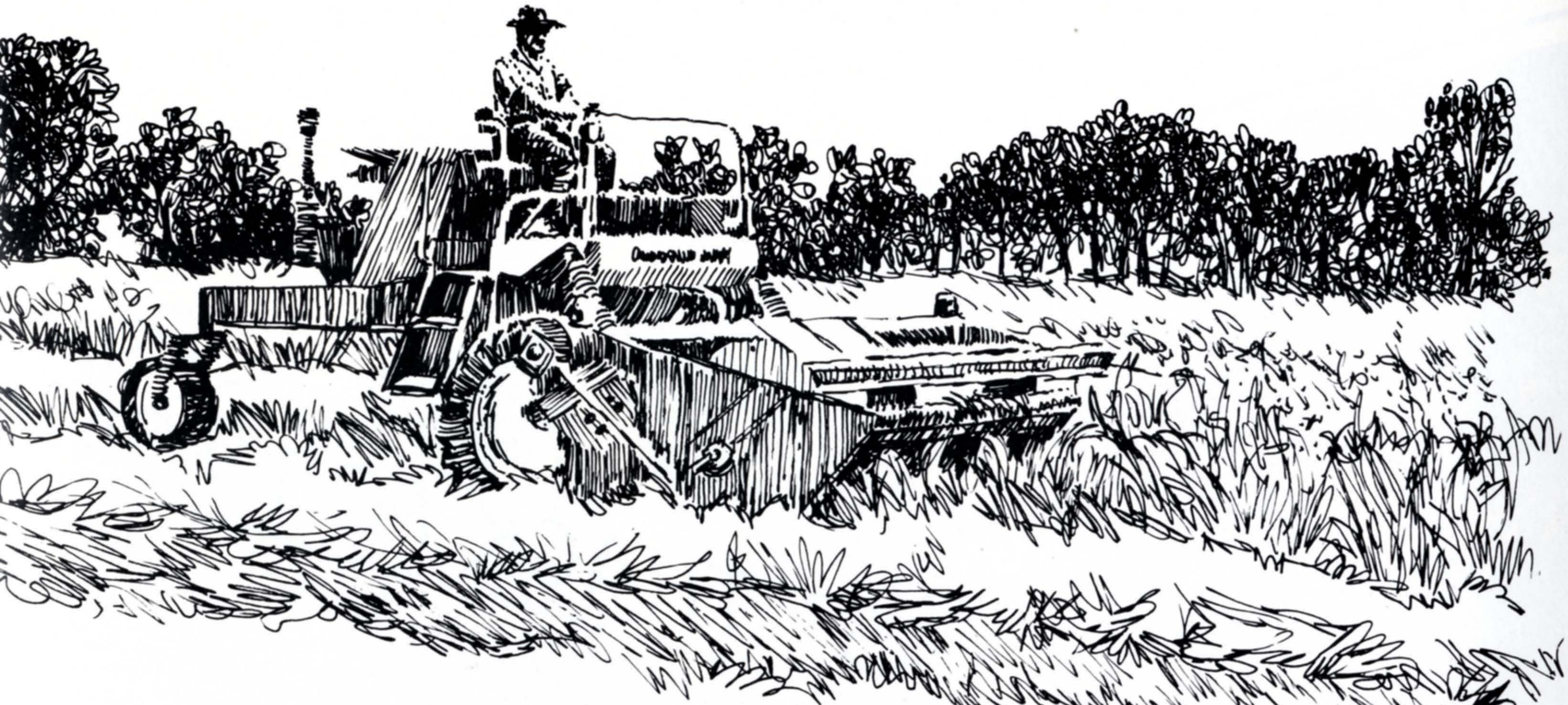
Land prices seemed to have leveled off during the past year. Projections are that they will remain stable through the country as a whole. Two things need to happen before the bleak land-value picture can improve. First, interest rates have to come down. Second, farm income prospects have to improve. When prospective buyers figure out the probabilities of those two events happening, they usually become discouraged.

Some individuals believe that the way out of the current farm troubles is to strike a compromise between the proponents of high supports and those who want no farm program at all. The compromise would advocate supports that are high enough to prevent disaster, yet low enough not to encourage greater production. In 1982, agriculture's share of governmental

**TABLE 1. Per Acre Costs (June 1982)**

| | Operating Costs | | | | | | | | Interest | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Direct Costs | | | | | | Depreciation | | | | |
| | Labor | Fuel | Repairs | Other | Taxes | SUB-TOTAL | | TOTAL | | | |
| TYPE OF OPERATIONS | | | | | | | | | | | |
| Plowing | 2.23 | 1.83 | 2.69 | | 1.48 | 8.23 | 7.76 | 15.99 | (The market fluctuations are presently too capricious to accurately account for these columns). However, see Table 2 for estimate of these costs. | | |
| Discing | 1.12 | .92 | 1.47 | | .82 | 4.33 | 4.23 | 8.56 | | | |
| Harrowing (twice) | .90 | .74 | .92 | | .54 | 3.10 | 2.66 | 5.76 | | | |
| Rodweeding | .60 | .50 | .79 | | .44 | 2.33 | 2.29 | 4.62 | | | |
| Fertilizing | | | | 9.00 | | 9.00 | | 9.00 | | | |
| Drilling | .67 | .55 | 1.36 | | .64 | 3.22 | 3.80 | 7.02 | | | |
| Seed | | | | 4.50 | | 4.50 | | 4.50 | | | |
| Trucking | 1.33 | .89 | 1.68 | | | 3.90 | 4.22 | 8.12 | | | |
| Spraying | | | | 4.40 | | 4.40 | | 4.40 | | | |
| Miscellaneous | | | | 5.00 | | 5.00 | | 5.00 | | | |
| Harvesting | 1.33 | 1.54 | 4.35 | | 1.68 | 8.90 | 11.96 | 20.86 | **Eqt.** | **Land** | **TOTAL** |
| Total cost per acre | 8.18 | 6.97 | 13.26 | 22.90 | 5.60 | 56.91 | 36.92 | 93.83 | 43.50 | 81.00 | 218.33 |
| Cost per bushel (1982)* | .27 | .24 | .44 | .76 | .19 | 1.90 | 1.23 | 3.13 | 1.45 | 2.70 | 7.28 |
| Cost per bushel (1980) | .26 | .23 | .39 | .75 | .19 | 1.82 | 1.07 | 2.89 | 1.18 | 2.33 | 6.40 |
| Increase (percent) | 4% | 4% | 13% | 1% | — | 3% | 15% | 8% | 23% | 16% | 13% |
| Cost per bushel (1976) | .21 | .09 | .23 | .70 | .13 | 1.36 | .65 | 2.01 | .53 | 1.60 | 4.14 |
| Increase (percent) | 29% | 166% | 91% | 8% | 46% | 38% | 89% | 55% | 174% | 69% | 75% |

*(30 bushel average)



outlays amounts to only about six-tenths of one percent of the federal budget. That is much less than some programs. Nevertheless, next year will bring even lower market prices if crop acres are not somehow taken out of production this year. Some manipulation of supports may be the answer.

The new set-aside programs for 1982-1983 are attempting to do just that. Things have moved along so well in the set-aside that USDA officials seem almost joyful. Early figures indicate that about 75 percent of the corn-milo base acres were enrolled and just over 71 percent of the barley-oats base. For wheat, the sign-up was around 84 percent of the base. Cotton and rice amount to about 91 percent. Final compliance is almost certain to be very high.

A successful set-aside program may remove enough land from production to strengthen commodity prices next year. Unless the Reagan economic policies aimed to lower interest rates and moderate inflation begin to succeed, however, the economic pain now felt by farmers will not ease.

ABOUT THE AUTHOR

Frank Condie, associate professor of Accounting, heads the USU Graduate Tax Program, concentrating on economic and tax issues for farmers and ranchers. He testified before the U.S. Senate Agricultural Committee on Crop Production Costs in 1978.

Condie will be conducting AICPA Seminars on Taxation of Farmers and Ranchers in Utah (August 5 in Logan) and California (November 22 in Bakersfield).

**TABLE 2. Summary of costs per bushel based on average 30 bushel yield (900 acres × 30 = 27,000 bushels available to be sold)**

| | Average Direct Expenses | Depreciation | Interest Eqt. | Interest Land | TOTAL | Market Price | Deficit |
|---|---|---|---|---|---|---|---|
| 1982 | 1.90 | 1.23 | 1.45[1] | 2.70[2] | 7.28 | 3.16* | 4.12 |
| 1980 | 1.82 | 1.07 | 1.18 | 2.33 | 6.40 | 3.60 | 2.80 |
| 1976 | 1.36 | .65 | .53 | 1.60 | 4.14 | 3.00 | 1.14 |

*Average of low protein (10½ and below) $2.98 and 11 protein $3.34 during month of May.

[1]$337,330 @ 18% for 10 yrs. = 72,870
(less principle) 33,730
39,140 ÷ 27,000 bu
= $1.45/bu

[2]1800 acres @ $425 = $765,000
$765,000 @ 13% for 25 yrs. = 103,600
(less principle) 30,600
73,000 ÷ 27,000 bu
= $2.70/bu

**TABLE 3. Schedule of Equipment**

| Description | No. | 1976 | 1980 | 1982 |
|---|---|---|---|---|
| Plow, 6 bottom 8'' | 2 | $ 7,200 | $ 14,200 | $ 20,000 |
| Disk, 14' | 2 | 6,600 | 10,600 | 13,000 |
| Harrows 36' with cart | 1 | 1,800 | 3,500 | 4,200 |
| Rodweeder 30' | 1 | 4,800 | 6,200 | 7,000 |
| Drill 14' | 2 | 9,600 | 18,600 | 18,500 |
| Harvester, hillside 18' | 1 | 48,000 | 78,000 | 98,000 |
| Truck 2 Ton w/bed | 2 | 19,200 | 34,000 | 38,000 |
| Tractor, Crawler (D4E) | 2 | 60,000 | 90,000 | 100,000 |
| Equipment Shed | 1 | 8,800 | 18,000 | 20,000 |
| Granary | 1 | 4,000 | 6,400 | 9,000 |
| Pick-up Truck | 1 | 4,000 | 6,500 | 9,600 |
| Total | | $174,000 | $286,000 | $337,300 |

# BUILDING A FAST TRACK FOR TOMA

1

2

## TOES


RICHARD F. HEFLEBOWER JR.
and ALVIN R. HAMSON

**FIGURE 1**
Tomatoes growing with clear and black polyethylene mulch and with clear polyethylene tunnels.

**FIGURE 2**
Polyethylene tunnel enclosing tomato plants.

**FIGURE 3**
Growth of tomato plant under clear polyethylene tunnel (June 22nd).

**FIGURE 4**
Growth of tomato plant under clear polyethylene tunnel (July 6th).

**A FULL-FLAVORED VINE-RIPENED TOMATO** is one of the most prized of all vegetables. Unfortunately, we may enjoy such quality tomatoes from commercial field production and home gardens in Utah for only a few months each summer. High quality, vine-ripened tomatoes may be grown in the greenhouse during the off season, but high energy costs have made greenhouse production uneconomical.

During most of the year, when ripe tomatoes are not available from local production in Utah, our major sources of fresh tomatoes are areas of warm season production such as southern California, Mexico, and southern Florida.

*Plastic mulches significantly increased plant yields.*

These tomatoes must be harvested and shipped when green-ripe so that they are sufficiently firm to withstand the shipment. They are ripened and become red in ripening rooms at terminal markets such as in Salt Lake City before being distributed to retail stores throughout the state. Prices are generally high and the table quality of tomatoes picked green-ripe never compares with that of fully mature, vine-ripened fruit.

Even during Utah's growing season, climatic conditions do not ideally satisfy the specific temperature requirements of tomato production. The optimum nighttime temperature requirements for fruit set in tomatoes range from 57° to 68°F. Very little fruit is set at temperatures between 50° and 57°F, and tomato pollen is sterile below temperatures of 50°F (Kloner 1973). Temperatures above 91.4°F effectively limit tomato production because of greatly reduced set (Shelby, Greenleaf, and Peterson 1978). Tomato pollen loses viability at a temperature of 107.6°F (Abdalla and Verkerk 1968).

Other climate constraints also severaly reduce Utah's tomato crop. Freezing, both in late spring and early fall, is a particular problem in the cooler mountain valleys and the high mesas of Utah, which have very short growing seasons. The quality of Utah tomatoes can be greatly reduced by chilling during the cool nights of fall when temperatures drop to less than 50°F and especially less than 40°F.

Extensive tomato variety trials have been conducted at the Farmington Research and Extension Center for the past ten years to identify early-maturing varieties of tomatoes that would do well despite a short growing season. Several such varieties as Presto, Early Girl, Early Cascade, and Moreton Hybrid have been selected as being early maturing tomatoes with good culinary quality. These varieties may be used to provide the first early tomatoes produced in areas having a moderately long growing season (14 weeks), but also may be grown in areas having shorter growing seasons (12 weeks). A number of other varieties mature two to three weeks earlier than main-season tomato varieties, but their quality is not desirable.

## Possible Solutions

Constraints on tomato production with respect to optimum temperatures are not unique to Utah. Researchers throughout the world have determined that mulching tomatoes with either clear or black polyethylene plastic will increase soil temperatures and result in earlier flowering, more flower clusters, and a higher percentage of early fruit set than are seen on tomato plants grown without plastic (Vandenberg and Tiesen 1972; Kloner 1973; Knavel and Mohr 1967; Honma, McArdle, Carew and Dewey; Carolus and Downes 1958). Plastic tunnels have been used in such areas as New South Wales, Israel, Michigan, Virginia, and the Willamette Valley in Oregon. The tunnels were applied either during the winter season when temperatures were relatively low, or in areas that combined relatively low elevations with cloud cover and low light intensity. Even under such conditions, however, clear plastic tunnels pose the problem of high temperature extremes beyond 107.6°F, which prevent germination of tomato pollen.

## Utah Results and Recommendations

This study was conducted near Utah State University in Logan, Utah to compare the effects of clear and black polyethylene mulches with those of clear polyethylene tunnels on the earliness of Early Girl tomatoes. Tomatoes were planted on May 30 to minimize the danger of killing frost. Plastic mulches and tunnels were immediately applied.

Treatment effects were measured by determining height of tomato plants, numbers of early blossoms, numbers of fruits set, and early yields from each of the three treatments compared to a controlled check.

The plastic mulches were applied by first planting the tomato transplants and then stretching the sheets of clear and black plastic over the rows and cutting X-shaped slits over the plants, which were then drawn through the plastic. The tunnels were constructed by using No. 8 galvanized wire cut to 60-inch lengths. These were pressed into the soil one foot on either side of the plants so that the wire hoops were 18 inches above the plants. Clear plastic, 5 feet wide and 20 feet long, was stretched over the hoops, which were placed 4 feet apart down the row with the ends and sides buried in the soil to securely hold the plastic in place. Five-inch slits were cut 3/4 inches apart at both sides of the tunnel near the top to maximize ventilation. Maximum and minimum temperatures were recorded within and outside of the tunnels in wooden boxes facing north to prevent influence by direct sunlight.

Heights of plants on June 8, 15, 23, 29, and July 6 and 13 are indicated in Table 1. Because of the high temperatures recorded in early July, the plastic tunnels were removed on July 8. The height of plants was greatest in the plastic tunnels. Plants on clear and black plastic were approximately the same in height and somewhat taller than the plants in the controlled check.

In Table 2 we compare the average number of blossoms per treated row to the average number of fruits set on June 30, July 14, and July 22. Though the tomatoes blossomed profusely under the tunnels, few blossoms set until the plastic tunnels were removed. The numbers of fruits set were generally higher for the plastic mulch treated plants than for the controls (see Figure 1).

The plastic tunnels were designed and operated in a way that would be practical under commercial culture. The ventilation of the tunnels was obviously inadequate, since every day that they were in place, their maximum interior temperatures exceeded the heat tolerance for optimum setting of tomatoes (91.4°F as indicated by Shelby et al. (1978)). The temperatures in the plastic tunnels exceeded 107.6°F on 11 out of 18 days (June 20 to July 7). At that temperature, tomato pollen is not viable. Figure 2 shows the yields of each treatment, and the effects of extreme temperatures on plants inside the tunnels.

For a home garden situation, it is recommended that plastic tunnels be applied earlier in the season (by approximately 10 days in Cache Valley or similar areas in Utah). Also, instead of slits for ventilation, the sides of the tunnels should be opened during bright, sunny days to provide ventilation, as was suggested by Kloner (1973). The temperatures measured within the clear plastic tunnels under our conditions of high elevation and high light intensity were acceptable until the temperatures reached approximately 90°F, at which point fruit set began to be reduced. At this temperature, the tunnels should be opened for ventilation and then closed again in late afternoon as the sunlight intensity degreases and the cooler temperatures of evening develop. Since our ventilation slits reduced the temperature within the tunnel to the ambient air temperature during the night, another advantage of eliminating ventilation slits would be to increase the night temperature for the tomatoes within the intact tunnels. Canvas, blankets, or other insulating materials might well be placed over the tunnels at night to better insure adequate temperatures for fruit set.

Early yields were significantly increased by the clear and black plastic mulches over the control at levels of 19 to 1. The early yield of the tomatoes grown until July 8 under plastic tunnels was reduced because of the high temperatures, which prevented fruit set within the tunnels (Table 3).

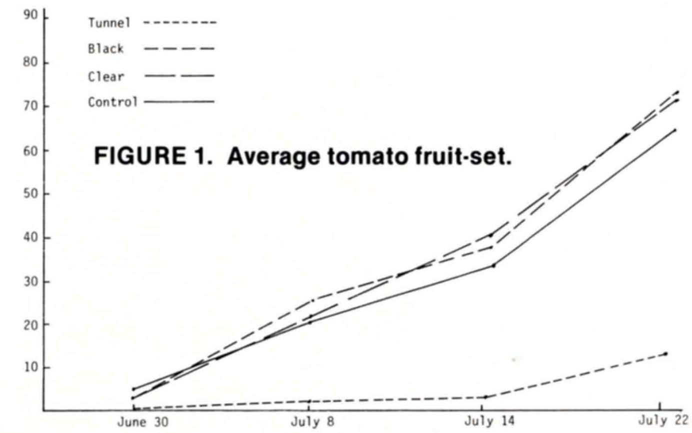



**FIGURE 1. Average tomato fruit-set.**

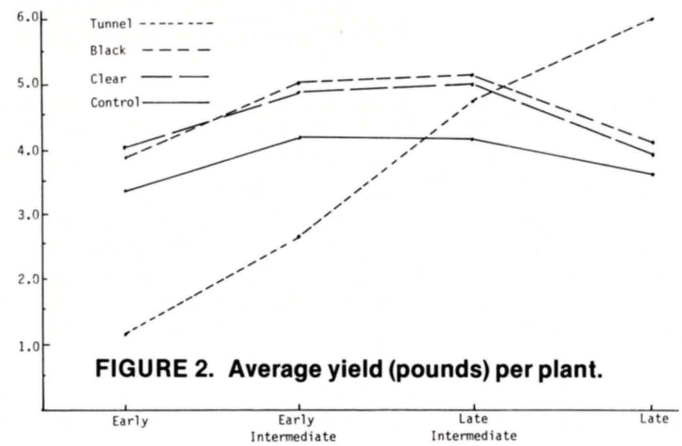



**FIGURE 2. Average yield (pounds) per plant.**

**TABLE 1. Heights of tomato plants in clear plastic tunnels, or on clear and black plastic mulches, compared to the control.**

| Date | Tunnel | Black | Clear | Control |
|---|---|---|---|---|
| June 8 | 5 in. | 5 in. | 5 in. | 5 in. |
| June 15 | 6 in. | 6 in. | 6 in. | 6 in. |
| June 23 | 9 in. | 8 in. | 8 in. | 7 in. |
| June 29 | 15 in. | 12 in. | 12 in. | 12 in. |
| July 6 | 16 + in.* | 16 in. | 16 in. | 14 in. |
| July 13 | 20 in. | 20 in. | 20 in. | 18 in. |

*Plants inside of the plastic tunnels were touching the top. All tunnels were removed by July 8.

**TABLE 2. Numbers of blossoms and fruits set under tunnels, over clear and black plastic mulches compared to the controls.**

| | Tunnels | Black Mulch | Clear Mulch | Control | |
|---|---|---|---|---|---|
| | No. of blossoms / No. set | No. of blossoms / No. set | No. of blossoms / No. set | No. of blossoms / No. set | LSD / LSD |
| June 30 | 18 | 13 | 14 | 11 | N.S. |
| | 0 | 2 | 2 | 4 | N.S. |
| July 8 | 23 | 37 | 34 | 32 | N.S. |
| | 1 | 25 | 21 | 20 | 4.5* |
| July 14 | 55 | 75 | 75 | 62 | 15.7* |
| | 3 | 38 | 40 | 34 | N.S. |
| July 22 | 80 | 73 | 79 | 60 | N.S. |
| | 19 | 75 | 72 | 64 | 21.8* |

*significant at the .05 level

**TABLE 3. Influence of clear plastic tunnels, and of clear and black mulches on early yield of tomatoes.**

| | Row Tunnels | Black Mulch | Clear Mulch | Control | LSD |
|---|---|---|---|---|---|
| Early | 1.11 | 3.90 | 4.07 | 3.26 | 12.95* |

*significant at the .05 level

*Attention to adequate irrigation is also needed.*

The value of the tomatoes produced per plant for each of the treatments was calculated by determining market value at each harvest date. This was multiplied by the quantity of tomatoes harvested, and the cost of the plastic mulches or the tunnel was then subtracted to give a net value per plant. The plants mulched with clear plastic gave the highest return ($5.90 per plant), followed closely by plants mulched with black plastic at $5.88 per plant. The control plants gave a return of $5.12 per plant, while those that were grown in the plastic tunnels gave a net return of $3.32 per plant. These net returns indicate a significant advantage to the use of clear and black plastic mulches in relation to the control plants, but they do not fully represent the potential of the plastic tunnels. A home gardener might well manage plastic tunnels in such a way as to enhance earliness and yield even more than could be expected from clear and black polyethylene plastic mulches.

Another advantage of plastic mulches and tunnels includes minimizing the normal leaching of nitrogen, as indicated by Jones, Jones, and Ezell (1977).

Knavel and Mohr (1967) suggested that deeper rooting of tomatoes occurs under clear plastic, while wide, more shallow rooting occurs under black plastic. They explained the difference in root distribution on the basis that soil mulched with clear plastic was warmer than soil mulched with black plastic or control soil and, as a result, more of the soil moisture was lost because of the evapotranspiration rates of tomatoes growing on the clear plastic mulch. It is important, therefore, to maintain an adequate moisture content under plastic mulches and especially under clear plastic mulches and tunnels. This may be accomplished with trickle irrigation, or by running irrigation furrows close to the sides of or underneath the plastic mulches. These furrows should be formed before the mulches are applied to insure adequate application of furrow irrigation. If it is possible to sprinkle the tomato plants early in the season, sufficient moisture would then penetrate around the plants and at the edges of the clear and black plastic mulches and from the sides of the plastic tunnels.

This study has not answered all questions concerning the use of plastic mulches or tunnels when growing early tomatoes. Our results were sufficiently promising, however, that commercial growers and home gardeners should want to further investigate such applications of plastics to induce early production of tomatoes in Utah.

ABOUT THE AUTHORS

Richard F. Heflebower Jr. is completing his MS in Agricultural Education (June 1982). He has a BS in Plant Science with an emphasis in Horticulture. He plans to continue his research and teach improved methods of fruit and vegetable production.

Alvin R. Hamson is a vegetable crops specialist in the Department of Plant Science. He has devoted 27 years to cultural research on and to breeding, and evaluating vegetable varieties. His objectives have included improving the yields and quality of vegetables that are particularly suited to the varied climates of Utah. Dr. Hamson obtained a BS from Utah State University in 1948, a PhD from Cornell University in 1952, and was a staff member of the Vegetable Crops Department at Cornell University for four years before coming to Utah. He has consulted on vegetable crop assignments in Thailand, Jordan, Syria, Zambia, the Gambia, and Colombia.

LITERATURE CITED

Abdalla, A. and K. Verkerk. 1968. Growth, flowering, and fruit set of tomato at high temperature. Neth. J. Agri. Sci. 16:71-76.

Carolus, R. L. and J. D. Downes. 1958. Studies on muskmelon and tomato responses to polyethylene mulching. Mich. Agr. Expt. Sta. Quart. Bul. 40:770-785.

Honma, S., F. McArdle, J. Carew, and D. Dewey. 1959. Soil and air temperature as affected by polyethylene film mulches. Mich. Quart. Bul. 41:834-842.

Jones, T. L., V. S. Jones, and D. O. Ezeil. 1977. Effect of nitrogen and plastic mulch on properties of troup loamy sand and on yield of 'Walter' tomatoes. J. Amer. Soc. Hort. Sci. 102:273-275.

Kloner, V. 1973. Problems and solutions in growing winter and spring tomatoes under plastics. Acta. Hort. 42:203-222.

Knavel, D. E., and H. S. Mohr. 1967. Distribution of roots of four different vegetables under paper and polyethylene mulches. Proc. Amer. Soc. Hort. Sci. 91:589-597.

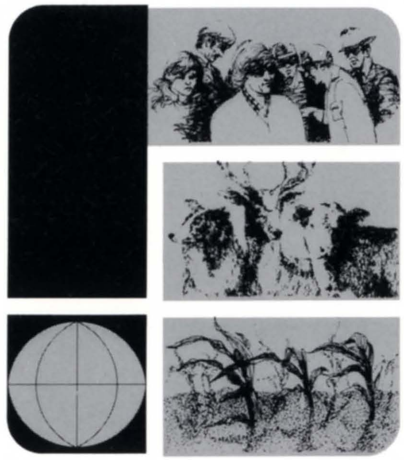
Morse, R. and L. Gayle. 1981. Slitted row covers for intensive vegetable production. The Veg. Grower News. 36(6):2-3.

Shelby, R. A., W. H. Greenleaf, and C. M. Peterson. 1978. Comparative floral fertility in heat tolerant and heat sensitive tomatoes. J. Amer. Soc. Hort. Sci. 103(6):778-780.

Short, T. H., and D. W. Kretchman. 1973. Wax paper tunnels for direct-seeded tomatoes. Ohio Report Research and Development. 58:40-41.

Sumeghy, J. B. 1970. Plastic covers increase tomato yield. Agr. Gaz. New South Wales. 81:569.

Vandenberg, J. and J. Tiessen. 1972. Influence of wax-coated and polyethylene coated paper mulch on growth and flowering of tomato. Hort. Sci. 7(5):464-465.



# fluoride in review

**IN HOLLYWOOD TERMS, IT WAS AN EXTRAVAGANZA.**

**IN SCIENTIFIC TERMS,**

**IT WAS AN INTERNATIONAL SYMPOSIUM.**

Participants and audience alike came from far and near to learn the world's most up-to-the-minute scientific view of fluoride.

Organized by James L. Shupe of USU's Animal, Dairy, and Veterinary Sciences Department, the May 25 through 27 International Fluoride Symposium drew scientists from around the U.S. as well as from Australia, Denmark, East Germany, England, Iceland, and Sweden. During those three days, the experts presented research philosophy and data, practical background discussions, and legal aspects of fluoride, its behavior and its management.

According to the reports, data is being accumulated that establishes more and more precisely how fluoride acts in animals and plants. We know what amounts cause what effects, how much is too much, and the most efficient ways to remove unwanted fluorides from water and industrial effluents. Research results have defined what levels of fluoride prevent dental caries and levels cause the disease called fluorosis. Other research is pointing toward the value of fluoride as a treatment and preventive measure for osteoporosis (softening bones).

The over 30 papers presented during the symposium will be published by the Utah Agricultural Experiment Station as a one-volume proceedings.

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